Command and Control Evaluation Workshop

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Command and Control Evaluation Workshop

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PREFACE

"How can we show that command and control system acquisitions will contribute to increased force effectiveness?" "The most difficult portion of the Strategic Defense Initiative is battle management." "How do we organize command and control for joint operations?" "How can we show that command and control system acquisitions will contribute to increased force effectiveness?" These are the types of problems that frequently perplex Department of Defense military and civilian leaders, analysts, and program managers. Questions of this type require the establishment of an evaluation structure firmly based upon Measures of Effectiveness (MOEs). Such measures must be tailored to the analytical application and provide credible results to decisionmakers. It is toward this goal that a Military Operations Research Society (MORS) Workshop about which this document reports was conducted at the Naval Postgraduate School, Monterey, in January 1985. The product of the Workshop was a draft of this report.

The reactions to the draft report were along two lines. The first was that the product was too abstract and remote from the practical decisionmaking process to be utilitarian; in effect, interesting theory, but so what? The second reaction, especially among the participants, was now that we have agreed on a structure for understanding Command and Control (C^2) in general, can we apply it to solve specific problems? These reactions amounted to viewing the glass of methodological utility as either half empty or half full. Both viewpoints suggested the need to put the product of the first Workshop to the test. That was done in January 1986 in a second MORS Workshop, "Evaluation of Command and Control Systems," which examined the following six current C^2 problems:

a. Army Tactical

b. Air Force Tactical

c. Navy Tactical

d. Joint Tactical

e. Air Force Strategic

f. Joint Strategic

The problems were chosen for their diversity and were intended to test whether the theory was in fact widely applicable in practice. The attendees at the 1986 Workshop were a mixture of those who attended in 1985 and first-time participants who were selected on the basis of their knowledge of the particulars of one of the six problems.

Was the consensus an overwhelming endorsement of this report and its recommended structure for evaluating C^2 systems? That would be too strong a claim. At one extreme was an unqualified approval and a conviction that as experience was gained and the evaluation technique applied, it would prove to be strong and reliable. At the other extreme was a tentative endorsement that the theory was better than nothing (that it could be worse than nothing was viewed as a possibility at the outset) and also, it was at least useful in focusing the analysis and structuring and evaluation. No one felt that the application of the methods, measures of effectiveness, or models was counterproductive, too rigid or formalized, or inherently defective in the light of the test on their problem from among the six. The general flavor of the criticisms was either that the guidance provided in this report would need to be adapted, modified, or relaxed to fit each particular case, <u>or</u> that the guidance needed further development, amplification, and detail. Since these two criticisms are antithetical, perhaps the report has struck about the right balance.

The 1986 report now in your hands is an improved version of the 1985 draft. It incorporates a small number of changes proposed during internal and external review, as well as the correction of technical errors. In a few places it benefits from the results of the 1986 Workshop.

The MORS and Workshop participants have made this report available in the expectation that it will be a useful guide. The content as regards definitions, selection and application of MOEs, the structure of C^2 models, and the formulation of C^2 mathematical analysis should serve as a common point of departure and aid in establishing a common language and set of analytical tools for analysts, whether their interest is research, development, procurement, or operation of a C^2 system. In particular, the report contains the Modular Command and Control Evaluation Structure (MCES). The MCES is designed to guide C^2 systems evaluation and architecture development within the Department of Defense.

ACKNOWLEDGEMENT

Administrative support for the publication of this document was provided by the MITRE Corporation.

The editors and Workshop participants wish to express their thanks for the support provided by the Military Operations Research Society, the Naval Postgraduate School, and The MITRE Corporation. Our thanks also are extended to the many decisionmakers who supported this effort with the commitment of some of their most valuable employees. In addition, members of 25 organizations* participated in this Workshop. The Military Services were represented by 3 Army, 7 Navy, and 1 Marine Corps participants. In addition, there were 3 JCS, 2 other Government, 9 MITRE, and 9 other contractor representatives at the Workshop.

Special thanks are extended to those members of the continuing cadre of experts who reviewed the prior drafts. We wish to thank Cdr. Paul Girard, NOSC; Dr. Harold Glazer, The MITRE Corporation; Griffin Hamilton, EASTAN Corporation; and Dr. Alexander Levis, MIT.

Finally, we wish to extend our specific appreciation for the administrative support of Ms. Natalie Addison of MORS and Barbara Rouleau of NPS, and the typing support provided by Barbara H. Walker of NADC, Zanie Bactad of NPS, and Faye Burke, Carol Lastuvka, and Wendi Williams of MITRE. Without their efforts, the Workshop would have fulfilled much less of its interactive and communication potential. In addition, Carol R. Oakes of MITRE provided the final editorial support so essential to the dissemination of this work.

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*ANSER, CNA, CAORA, DCA, DSI, EASTAN Corporation, ESD/XRX, IBM, MCTSSA, MIT, MITRE Corporation, NADC, NAVAIR, NAVELEX, NOSC, NPS, OJCS, ONR, RADC, RAND, SAIC, Sperry Corporation, Stanford University, Tradoc Research Element Monterey, and USA TORA.

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CHAPTER 1

INTRODUCTION

by
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1.0 FOREWORD

Command and Control (C^2) is central to warfighting. A great investment is being made to improve the application of automation and communications technology to C^2. The incoming Reagan administration's number 1 defense priority was C^2. But what does C^2 do? How do we know it does what we think or hope it does? Does more of it, or improvements in it, pay off by increasing force effectiveness? These questions place the issue directly into the realm of evaluation.

C^2 is an interdisciplinary field. There is no single professional community that encompasses both aspects of the C^2 environment, the operational and the technological. In the operational environment, people are the most important element, but technological advances have diverted attention to hardware.

The past has been characterized by a lack of agreement among analysts and decisionmakers over a number of important issues. Among these were:

a. The use of a set of consistent definitions relevant to both C^2 systems and the measurement thereof.

b. The relationship between a C^2 process and the physical entities that are part of the C^2 system.

c. The specification of an appropriate model of C^2.

d. The appropriate integration of the selected C^2 model, measures, methods, and mathematics.

e. The way in which the C^2 model may be incorporated in a specific problem.

f. The relationship between the decision to be supported and the analysis itself.

It appears to us that what is needed is an integrated, balanced approach. This report initiates the establishment of such a C^2 evaluation approach. Such a roadmap for the evaluation of C^2 systems should be useful in the determination of both the contribution of C^2 systems to warfighting capability and the selection of a candidate C^2 system or architectural configuration from among competing alternative designs.

This report is written in the hope that it will provide a ready reference to the understanding and use of evaluation measures for C^2.

Readers may be decisionmakers involved in budgetary or programmatic decisions, design engineers, or operational officers. It is believed that a Measures of Effectiveness (MOEs) concept may also help non-analysts understand what such studies mean to them. Unfortunately, the analytic community has not always articulated its technical framework and results in a manner which can be safely and unambiguously interpreted by the layman. Careful definition and structuring of analyses lead to results which, when expressed clearly, can be readily understood.

To that end, it is our intention that this report will provide readers with:

a. A compendium of terminology and references.

b. An important partition of the field into C^2 process and C^2 system.

c. A structure of the field of C^2 MOEs (dimensions).

d. A conceptual model(s) of the C^2 process and the function of MOEs within the model.

e. An appreciation of the complexity of mathematically modeling C^2 and its MOEs.

f. An understanding of the data collection necessary to specify MOEs.

g. Exposure to the application of MOEs.

1.1 Background

Important efforts have been made by small groups of specialists over the last decade in broadening our perspective on both the substance of C^2 and the evaluation of systems created to carry out this function. As a result, a meaningful beginning has been made in the development of a theory of C^2 and its relationship to a theory of combat. These efforts have been scattered among all parts of the military establishment. While there have been periodic attempts to integrate the results of these activities into some comprehensive form, it has usually not been possible to document and disseminate these efforts. Thus the community dealing with these issues has continued to express a need for a reasonably accessible source of information conveying state-of-the-art knowledge of such matters.

The initial impetus for this effort was one of those integrating attempts referred to above. It was triggered by a challenge from General Eaglet in his role as Deputy Chief of Staff, Plans and Programs, Headquarters, Air Force Systems Command. Specifically, General Eaglet invited Air Force planners to determine the force effectiveness of C^2 systems. This meeting, called the "Measures of Effectiveness for C^3 Evaluation Symposium," took place at The MITRE Corporation in Bedford, Massachusetts, on February 28 to March 1, 1984.

It seemed appropriate to the symposium's organizers to direct the expert knowledge of the analytic community to arrive at a synthesis of the current state of the art. The symposium's general goals were established to:

a. Determine a baseline of common principles, including:

   1. Definitions.

   2. Approaches.

   3. Conceptual models.

b. Identify what else is known.

c. Determine what needs to be learned.

In a series of organizational meetings, the 1984 Symposium chairpersons, Dr. Ricki Sweet and LTC Thomas Fagan III, and working-group session chairpersons, Dr. Zitta Z. Friedlander, The MITRE Corporation, Griffin F. Hamilton, EASTAN Corporation, Linda Hill, SAIC, Dennis Holstein, LOGICON, and Richard Hu, Naval Sea Systems Command, developed the method used to address the overall objective. Four working groups were formed, each to discuss in parallel the same topics. The topics were:

a. Working Definitions.

b. MOE Identification.

c. Evaluation Techniques.

Panels were formed to address the convened Symposium after each working session. Each working-group chairperson presented the results of their deliberations. On the first day, it became evident that simple solutions would not emerge from the deliberations of such complex topics. Therefore, a fourth topic, Summary, was added to include an overall appraisal of the current status and future course of this type of MOE analysis.

Deliberations of the 1984 Symposium were reported to the 52nd Military Operations Research Society (MORS) Measures of Effectiveness Working Group in June 1984, with an audience of over 100 attendees. Presentations were made by the working-group chairperson as well as LtCol Edward C. Jonson, Director of Long Range Planning, ESD/XR, Ted Jarvis, The MITRE Corporation, and Dr. Morton L. Metersky, Naval Air Development Center.

Based upon the critiques and discussions in the Measures of Effectiveness Working Group, it was suggested MORS sponsor an interim workshop for selected members and the analytic community. The "organizating committee," Dr. Ricki Sweet, also the chairperson, MORS C^3 Working Group, Dr. Michael G. Sovereign, Chairman, Joint C^3 Program, Naval Postgraduate School (NPS), and Dr. Morton L. Metersky, developed a proposal for a MORS-sponsored C^2 MOE Workshop.

This Workshop was chaired by Dr. Sweet, co-chaired by Dr. Metersky, and hosted by Dr. Sovereign. It was convened at the Naval Postgraduate School in January 1985. In addition to the organizing committee, several other key people were heavily involved in the Workshop and in the development of this document. They were Dr. William Foster, The MITRE Corporation, Dr. Stuart Brodsky, Sperry Corporation, Walker Land, IBM, Richard Miller, now OSD, Charles Smith, now Nichols Research Corporation, and Dr. Conrad Strack, Defense Systems, Incorporated.

These people also participated in the development of a "strawman" which guided the deliberations of the MORS-NPS Workshop. Using this strawman under the direction of this group, the Workshop attempted to engage both analysts and C^2 theorists in a structured dialogue on the development, computation, and application of C^2 MOEs as tools for the evaluation process.

During the Workshop a cadre of designated Intergroup Coordinators (ICs) provided the interface for the working groups, each of which worked on an independent portion of the problem. The major function of the ICs was to bring ideas, thoughts, and concepts to the attention of other working groups by circulating among them as they saw fit. Table 1-1 provides a list of Workshop participants. ICs are indicated therein. Each participant also contributed materially to the preparation of this document during the Workshop.

TABLE 1-1

WORKSHOP PARTICIPANTS

Dr. Ricki Sweet, MITRE Chair
Dr. Morton L. Metersky, NADC Co-Chair
Dr. Michael G. Sovereign, NPS Host

<u>Applications Working Group</u>

Dr. William Foster, MITRE, Chair
COL Robert Allison, USA, JCS
Robert Choisser, DCA
MAJ Bernard Galing, USA, TREM
LtCol Edward C. Jonson, USAF, ESD
Dr. S. Z. Mikhail, NOSC
MAJ Larry Rhoads, USMC, MCTSSA

<u>Conceptual Model Working Group</u>

Walker Land, IBM, Chair
Ted Bean, MITRE
Leon Godfrey, CAORA
Judy Grange, SAIC
LCDR Don Newman, NAVAIR
Tony Snyder, RADC

<u>Measures Working Group</u>

Richard Miller, TORA, Chair
Dr. Harold Glazer, MITRE
Linda Hill, SAIC
Charles Smith, ANSER
Capt Bruce Thieman, USAF, JCS

<u>Mathematics Working Group</u>

Dr. Stuart Brodsky, Sperry, Chair
Dr. Alex Levis, MIT
Dr. Tony Richardson, Daniel Wagner Associates
Dr. Conrad Strack, DSI
Dr. Edison Tse, Stanford
Dr. Clairice Veit, RAND

<u>Intergroup Coordinators</u>

Edward C. Brady, MITRE
Dr. Norval Broome, MITRE
Dr. John Dockery, JCS
Dr. Zitta Friedlander, MITRE
CDR Paul Girard, ONR
Griffin Hamilton, EASTAN
Dr. Joel S. Lawson, Jr., NAVELEX
Dr. Martin Leonardo, NADC

*All affiliations as of meeting date.

A staff provided the necessary clerical and administrative support. This staff included Natalie Addison, MORS, Barbara Walker, Naval Air Development Center, Zanie Bactad, NPS, Major Bernard Galing, NPS, and Commander Joseph Stuart, NPS.

The essence of these deliberations was briefed at the 53rd MORS in June 1985. Viewgraphs used at the briefing can be found in Appendix A. Review of the preliminary materials was solicited from the attendees, members of the MORS Board of Directors, participants of the Workshop, and other interested parties.

This report represents the current thinking of the experts who participated on a voluntary basis in the two meetings described. As an integrative presentation, it should be viewed as an initial formulation of the necessary components of an evaluation architecture for C^2. When expanded upon, this report and successor documentation will represent the explication and application of the concept and methodology for the evaluation of C^2 systems.

1.2 Objectives

1.2.1 This Report

Evaluations of C^2 systems are undertaken for a variety of different purposes. Therefore, it is expected that this report will be of interest to several different groups of readers, categorized as follows:

a. Analysts working in the Command, Control, and Communications (C^3) field. Experienced analysts are already aware of the problems that are raised but may benefit from their compilation as a reference. Beginning analysts could consider it as part of their education.

b. Those who work in design, development, and test functions producing and using C^2 evaluation measures and who then need to be familiar with their context.

c. Decisionmakers in the C^2 field, involved in doctrine, development and force structure, and operational planning and execution who need to be aware of the options available for measurement, the general nature of the difficulties and, most importantly, the caveats concerning the use of such measures that should be brought to their attention.

1.2.2 Overall Effort

There are many uses for MOE analyses. The tendency of military system development agencies is to use MOEs while seeking answers to acquisition issues. Research and Development (R&D) organizations look to MOEs as a way to validate systems design and to correct current and long-term deficiencies. User commands need solutions to operational problems and look to MOEs as a way to help them in this.

Programmatic decisions starting in the conceptual development phase determine whether or not a C^2 system will be funded. MOEs play a part in providing the necessary analysis supporting decisions to approve funding for C^2 programs. They provide military system development agencies with a tool to help obtain approval for programs, and provide a link to the assurance of whether a system will fulfill operational requirements.

Acquisition management activities have a continual concern for the proper use and interpretation of performance measures. This is true at the component equipment level and in the evaluation of the contributions of such components to the performance of large aggregates of equipment, the interaction of said aggregates and people, and the contribution of these to an ability to carry out a mission.

Design decisions can also be significantly affected by data derived from measurements. These data can provide an indication of how well a proposed system can perform and what design changes may

be desirable to effect increases in capability. Whether this information is derived from laboratory test and evaluation, operational test and evaluation, or from feedback of exercises or operations, it frequently involves the use of MOEs and supports efforts to improve C^2 systems.

Finally, MOEs can be applied to procedural or operational C^2 systems. Through evaluation data and feedback, operational commanders and developers of tactical and strategic doctrine can obtain an indication of the effectiveness of existing doctrine and can propose modifications to improve capability. Design recommendations to development agencies can be another result of MOE analyses. Judicious use of operational systems requires an understanding of how to measure performance and relative contributions to mission success. It also requires an appreciation of how such measures may vary depending upon alternative arrangements and uses of systems and upon different operational contexts. This type of knowledge coupled with attention to deficiencies provides a basis for doctrine development and force structure activities.

It is not surprising that the need for a global model of C^2 and associated MOEs is not completely accepted. Decisionmakers may look to MOEs to reinforce their particular needs. This frequently results in an emphasis on a single-purpose model in contrast to a general conceptual model. Program or acquisition managers, for example, deal with present systems or those in development in a specific mission area. Therefore, they are most concerned with evaluation of systems under procurement or in operation. They are interested in improving effectiveness of the system being procured, or in the case of an operational system, assuring that the system will, for example, increase its ability to leverage offensive and defensive weapons systems. These immediate concerns will always be in opposition to the more universal concern for the global models

and their associated MOEs.* Overall, MOE analysis must deal with long-range global problems, as well as near-term issues for design, programmatic, and operational applications. Table 1-2 summarizes the effects of MOEs on decisions.

While evaluative measures are continuously used in the above contexts, as well as in several other related areas, it is normally the case that an individual analyst or decisionmaker only needs to use a subset of such measures for any particular problem at hand. This frequently results in an emphasis on a single interpretation of effectiveness measures in contrast to a broadly based perspective on such measures. In fact, many users of such measures do not recognize the need for a broadly based understanding of a theory of such measures. Without the uniform broad theory to draw upon, and with the practical need to get the problems being addressed solved, most analyses must take the pragmatic approach of a narrowly constrained bottoms-up perspective. Our objective, to provide a cohesive top-down perspective, should lead to better evaluation for less time and effort.

1.3 Overview of This Document

This document is organized in a manner similar to the format used in the Workshop. Thus it is a collection of chapters produced by committees. For this reason, references to existing material are not provided despite their relevance. Coordination of the chapters was specifically attempted but was not completely effective. Differences in nuance and perspective are still evident. However, there is an overall structure. Following the introduction in Chapter 1, Chapter 2 presents definitions, and the overall architecture is discussed in Chapter 3. Chapter 4 directs attention to the decisionmaker's need for C^2 measures in his applications environment, while Chapter 5 presents the conceptual process model

*MOE is used here in a generic sense.

TABLE 1-2

EFFECT OF MOEs ON DECISIONS

ANALYSIS OBJECTIVES	EFFECTS	USED BY
Conceptual Development	Planning and Doctrine System Requirements	Systems, Operational Commands, Requirements Analysts
Acquisition	Procurements System Specifications	System Commands Program Managers
Design	System Capability Choice of Technology Redundancy	R&D Scientists Design Engineers System Commands
Operations	Development of Doctrine and Tactics	Operational Commands and Commanders
	Measuring Warfighting Capability System Deficiencies	Operational Commanders Operational Planners Schools, System Sponsors

of C^2. This is the basis for the work that follows. It establishes the C^2 functions that must be performed and evaluated. Chapter 6 frames the C^2 model with the analytical or evaluation process, discusses techniques for obtaining measurements, and gives examples. Chapter 7 provides a theoretical statement of the problem which gives guidance on the approach to measurement regarding sufficiency and precision. A short summary is presented in Chapter 8. Finally, Appendix A contains briefing materials used at the 53rd MORS. Appendix B presents a list of the acronyms which we have attempted to use minimally in this document.

CHAPTER 2

DEFINITIONS

by
Edward C. Brady
Dr. Morton L. Metersky
Dr. Michael G. Sovereign

2.0 INTRODUCTION

Within the military analytic community there have been long-term debates regarding an appropriate definition for the terms "measures of effectiveness" and "command and control." It is unlikely that the efforts of this Workshop resolved these issues. Nonetheless, there was need among the participants and in communicating the efforts of the Workshop to others to have an understanding of what these terms mean. Therefore, definitions are presented for the following terms: command and control, C^2 systems, physical entities, structure, C^2 process, dimensional parameters, measures of performance, measures of effectiveness, and measures of force effectiveness. These definitions were accepted and used by most of the Workshop participants.

2.1 Command and Control

The military activity of interest to the Workshop was "command and control." Command and control has been used as a broad concept whose breadth has been denoted by the use of terms such as C^2; C^3; Command, Control, Communications, and Computers; and Command, Control, Communications, and Intelligence (C^3I). Over time and in different parts of the military community, this term has also had a variety of narrower definitions (for example, sometimes the distinction is made between "command and control" and "combat direction," and sometimes a distinction is made on the basis of what is "embedded" or "non-embedded" in sensor and weapons platforms or systems). It is the intent of this Workshop to consider "command and control" in as broad a generic sense as possible in the belief

that a broadly based, generic, top-down approach will be of value to the analytic community and to the readers and users of analytical reports. Thus, throughout this report the term "C^2" should be taken to mean as broad a concept as is useful for the analysis being undertaken or discussed. This means that there will be some variation of its definitional boundaries depending upon the analytical questions being pursued. This is common practice in almost all forms of military analysis. It is agreed that this term does not include weapons functions, but it may or may not include sensor functions. It is not felt that this flexibility obstructs progress in developing a theory of C^2, a model of C^2, or the development and use of analytical measures. (Several Workshop participants did not accept this view).

The spirit of this definition is well captured by the approved Department of Defense (DOD) definition found in Joint Chiefs of Staff (JCS) Pub 1:

> "The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of his mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of his mission."

2.2 C^2 Systems

Furthermore, it is felt that in order to theorize about C^2 and to construct a model of C^2, it is useful to have a definition of "C^2 systems." It is thought to be important for evaluation applications that this concept be viewed as having three components: "physical entities," "structure," and "C^2 process."

a. Physical Entities - Refers to equipment (computers and peripherals, modems, jammers, antennas, computer local-area networks), software, facilities, and people.

b. Structure - Identifies the arrangement and interrelationships of physical entities, procedures, protocols, concepts of operation, and information patterns. (This frequently reflects doctrine and may be scenario dependent.) Such arrangements are often spatial and temporal.

The JCS Pub 2 definition of a command, control, and information system captures the intent of our definition of C^2 systems:

> "An integrated system comprised of doctrine, procedures, organizational structure, personnel, equipment, facilities, and communications which provides authorities at all levels with timely and adequate data to plan, direct and control their operations."

c. C^2 Process - In addition, it is important to understand that "C^2 process" is "what the system is doing" and reflects functions carried out by the C^2 system--sensing, assessing, generating, selecting alternatives, planning and directing.

2.3 Boundaries

The "boundary of a C^2 system" is defined as a function of the analysis at hand, and is the delineation between the system being studied and the environment. Thus, while the definitions are reasonably rigorous, they apply in the context of the system boundary (including its environment). An MOP in one analysis might well become an MOE in another. For example, if the National Command Authority and its information system (the Worldwide Military Command and Control System) is the C^2 system being evaluated and a conventional war is being fought, the force elements of the battle, e.g., battle groups at sea, corps in the field, and wings of aircraft, can be viewed as weapons systems. Thus, MOFEs would be relative to the armed forces achieving their mission in some theater of action. In another analysis, each of these "weapons systems" alone could become

the force which is accomplishing its unique mission and to which an analyst must relate his C^2 MOEs. The Figure 2-1 diagram depicts the relationship between MOEs and MOFEs.

2.4 Measures

The analytical activity of interest to the Workshop was measuring and evaluating the behavior/performance of the C^2 system in a context appropriate to the problem being evaluated. To be generic, it is essential that postulated measurements be adapted to the analytical question being pursued and to the boundary definitions of the C^2 system being investigated. In dealing with this issue the analytic community has developed a set of terms related to one another:

a. Dimensional Parameters.

b. Measures (Variables) of Performance (MOPs).

c. Measures of (C^2 System) Effectiveness (MOEs).

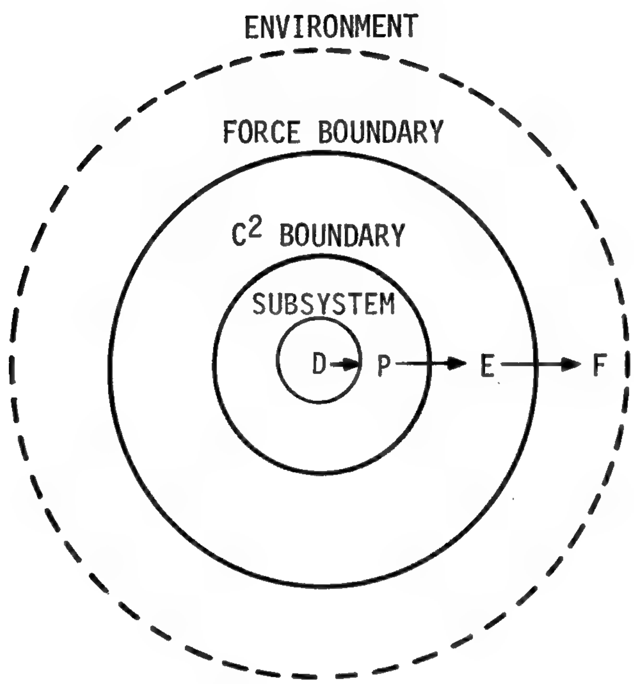
d. Measures of Force Effectiveness (MOFEs).

The three components describing a C^2 system must operate within an operational and physical environment which is represented in Figure 2-1 as outside the force boundary. Effects of environmental considerations are subsumed within these components.

Consensus has not been achieved on how these measures can be stringently defined so as to be comprehensive and distinguishable from one another. Therefore, the following definitions were presented for use in the Workshop:

a. <u>Measured/Specified Inside the Boundary of the C^2 System</u>:

1. <u>Dimensional Parameters</u> - Properties or characteristics inherent in the physical entities whose values determine system behavior and the structure under question even when at rest (size, weight, aperture size, capacity, number of pixels, luminosity).



WHERE:

D = DIMENSION
P = PERFORMANCE
E = EFFECTIVENESS
F = FORCE OUTCOME

NOTE: TIME CAN BE A PARAMETER OF ALL (D, P, E, & F)

FIGURE 2-1
MEASURE RELATIONSHIPS

2. MOP - Closely related to inherent parameters (physical and structural) but measure attributes of system behavior (gain throughput, error rate, signal-to-noise ratio).

b. Measured/Specified Outside the Boundary of the C^2 System:

1. MOE - Measure of how the C^2 system performs its functions within an operational environment (probability of detection, reaction time, number of targets nominated, susceptibility of deception).

c. Measured/Specified Outside the Boundary of the Force:

1. MOFE - Measure of how a C^2 system and the force (sensors, weapons, C^2 system, and structure) of which it is a part performs missions (contribution to battle outcome).

MOEs are measured relative to some standard, which is often implicit. Often implied is "how a perfect C^2 system would perform," i.e., the probability of detection compared to the number of detections theoretically possible, giving a perfect system a probability of 1. Varieties of such standards are used, including, for example, how a "baseline" system performs, or compared to mission requirements.

A distinction is made between the terms MOE and MOFE. An implication of this distinction is that many other factors contribute to whether an improvement in C^2 system MOEs results in improvements in MOFEs. For example, increasing target detections when no further ammunition is available to weapons, or increasing the rate of target detections when the rate of fire cannot be increased, or improving post-strike connectivity to weapons which are all vulnerable to first-strike destruction will not improve MOFEs.

Relating MOEs to MOFEs and thereby evaluating C^2 systems is a very complex issue. As one issue to be accounted for, it is noted that MOEs themselves, as well as MOFEs, are related to the operational context and to assumed enemy actions. As such, they are inherently scenario dependent.

This also means that it may be the case that measures used for one purpose, e.g., acquisition management, are inappropriate to evaluate C^2 system performance for another purpose, e.g., doctrine development. It is unlikely that a single set of measures can be used in each application, or that each measure can be used in every application. Therefore, the measures must be carefully chosen from among potential candidates and related to supporting decisions to be made.

2.5 Summary

In most cases, parameters, when related to physical entities, are as objective and quantified as they would be in a hard science or engineering sense, and can be measured or estimated. MOPs also sometimes are subjective and qualitative, e.g., ordinal ranking by "experts," and may or may not be assigned numerical values. MOEs and MOFEs are heavily judgmental even when they are numerical, since choosing system boundaries, particular functions to be evaluated, and the reference standards, and making other such judgments can greatly influence particular numerical calculations. Even when based on models, they are highly dependent on the model assumptions, simplifications, values of input parameters, and the selection of output measures to be estimated.

In summary, working definitions have been suggested for C^2, C^2 systems, physical entities, structure, C^2 process, and their related measures (dimensional parameters, measures of performance, measures

of effectiveness, and measures of force effectiveness). Additionally, it has been emphasized that these measures are distinguished by where they are "measured" relative to the boundary of the system under consideration, including evaluation scenario and other environmental factors such as hostile capabilities, assumptions about intelligence and knowledge, etc., which are also discussed.

CHAPTER 3

EVALUATIVE STRUCTURE - AN ARCHITECTURE

by
Dr. Ricki Sweet

3.0 INTRODUCTION

The evaluation "Architecture," as used in this chapter, refers to the relational structure between building blocks established for this Workshop and discussed in the remaining chapters in this report: "Applications and the Need for C^2 Measures," "Model," "Measures," and "Mathematics." The building blocks themselves are generic. In any specific evaluation, the generic block will be replaced by alternatives which meet stated criteria for each block in the analysis.

This chapter provides an extensive summary of the chapters following. A preliminary version of this chapter appears in the June 1985 Phalanx. The four working groups at the Workshop each addressed a different part of this "Architecture" for the evaluation of C^2 systems.

The boundaries for any study are set by the "Applications." The general conceptual model specifies the range of contexts within which problems may be analyzed; thereupon the C^2 process model addresses the functionality of interest. A set of "Measures" is associated with C^2 and is derivative of the applications. A mathematical formulation, "Mathematics," appropriate for C^2 analyses, underlies this architecture.

The focus of the Workshop was to develop a framework that could be used for evaluation of the C^2 systems. This chapter identifies this structure and attempts to answer the questions: "What did we accomplish?" and "What do we still need?"

3.1 Architecture for Evaluations - What Did We Accomplish?

This Workshop was one of a continuing number of occasional efforts to build a science of C^2 evaluation using "measures of effectiveness." Through this forum, the level of awareness among analysts and decisionmakers as to the lack of consistency and structure was raised. Moreover, perhaps because of the new nature of C^2, it is evident that very little work is being done to correct these deficiencies.

We believe that an architecture for evaluation such as presented here is most needed in the difficult task of preparing comparable measures about unlike systems which are competing alternatives for budget resources.

Figure 3-1 is a representation of this structure. The application will be used to specify the scope of the analysis. A conceptual model would further specify the important modules for development and generation of MOEs used to support decisions related to the Application. Data sources, parameter types, and mathematical formulations would follow. The ultimate goal in a specific evaluation would be to identify the mix and match of applications, boundary conditions, models, measures needed, and techniques for data collection. Such a menu approach will facilitate the structuring of analyses.

This chapter also identifies some of the specific contributions of each working group which impact on the architecture. It must be emphasized that the application, rather than any specific model, is the driving force. The application is the blueprint for elaborating the specifics of the architecture without the need for further analysis in making specific decisions tied to the Application. Thus the analysis is shaped by decisions it is intended to support.

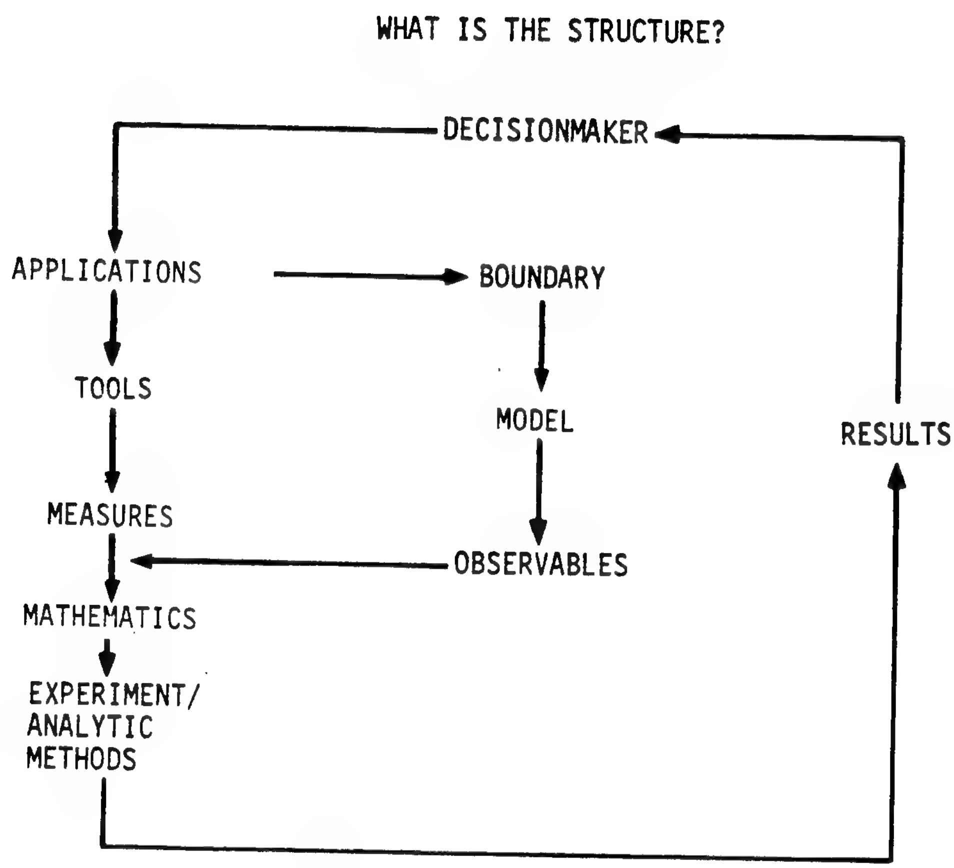


FIGURE 3-1
STRUCTURE — ARCHITECTURE

3.1.1 Applications

The specific focus of measures of effectiveness analyses depend upon the objectives of the study. The "Applications" working group identified four sets of decisionmaker environments objectives which may require distinct approaches: concept definition, development, acquisition, and operations. These terms, used in the DOD 5000 series, describe the life cycle phase of military systems. Their inclusion in DOD documentation emphasizes the fact that these are different phases where decisions that DOD personnel must make occur, and that our analyses must support.

Individual or comparative C^2 system assessments may be required within these Applications.

In an individual assessment, we ask: "Can we determine the contribution of a specific C^2 system to command and control as exercised by military commanders or mission performance?"

On the other hand, the extreme case of comparative analyses is reflected in the question: "Can we compare all DOD physical systems, from bombs to computers, across all Services, commands, and mission areas?" These latter questions are asked in various tradeoffs such as those employed in the POM cycle.

The specific analytical questions being addressed, together with the applications area to which the study is directed, determine the boundaries to be used. The more specific the tasking statement, the more passive the boundary. If the tasking is too broadly stated, boundaries used for establishing limitations of scope of the analysis are likely to be too encompassing, making the analysis intractable or so lacking in specifics as to not be supportive of decisionmaking. This approach and its limitations are common to systems approaches to analysis in many different disciplines. If the tasking is overly narrow for the decision being supported, however, answers to suboptimal questions are derived.

The application thus directs us to the focus of the analysis within a general conceptual model. The general model is made specific with regard to physical systems, processes, and level of aggregation. The general conceptual model of C^2 is viewed as the foundation for C^2 system evaluation.

From this perspective, the tools to use become clear. These tools are the measures and the mathematics. Next, we will discuss the C^2 system model.

3.1.2 Model

For much of this Workshop and its predecessor, the 1984 C^3I MOE Symposium, the search was directed toward identifying a generic model. "Generic," as used here, refers to a model of sufficient generality to be applicable regardless of mission area, Service, command, or C^2 system. Additionally, the model must accommodate the entire C^2 system, including physical entities, structure, and its environment, especially weapons systems. Functionality would be a prime focus. Time, space, geography, and hierarchical relationships could be imbedded in or in the environment of the model. Such a model should be capable of relating any of its components to overall force effectiveness.

The Workshop defined a C^2 system as a combination of structure and physical equipment. The C^2 process is what the C^2 system does. How we analyze the process and the system within an environment, as well as what aspects we specifically study and the complexity of the model, are functions of the application. Unfortunately, it is frequently the case that different parts of our C^2 community evaluate one or the other of these two aspects, rather than both.

To handle either individual or comparative C^2 system assessments in an inclusive context, a detailed model may be needed. The level of analytical detail depends upon such factors as the criticality of the decision, the time available for the

analysis, and the phase of the system life cycle which the model supports. The use of boundaries substantially reduces the size and focus of the model, especially with highly complex models.

This working group emphasized one part of the C^2 system, namely, the C^2 decision process. This perspective is based upon the assumption that a major function of C^2 control systems is to help make better decisions, and that a clear statement of this perspective is badly needed.

Attempts were made to extend the resulting C^2 decision process model to hierarchical systems, two-sided systems, and temporal considerations, with some success, indicating potential payoff in the next iteration.

3.1.3 Measures

MOEs and MOFEs are the basic terms for representing "effectiveness." The precise combination of measures used depends upon the analysis objectives, conceptual model, boundaries, and the nature of the analysis. The application determines whether to evaluate the force effectiveness or simply the performance of a given system. The level of the C^2 analysis impacts upon the specification of the boundaries for the model. However, there are significant problems with availability of the data. For example, no objective data represents the entire generic model. Both quantitative and qualitative data must be included. Further, depending upon how broadly construed the analysis objective is, we must recognize that certain data, for example, in the Strategic Defense Initiatives arena, is unlikely to be available for analysis purposes. Under such circumstances, simulations and other techniques could provide substitute essential data. Even these data sources may not be available, depending upon the time frame of the analysis or the size of the problem. Furthermore, MOEs and MOFEs typically require analysis of two opposing forces and frequently too little data, if available, about the enemy.

3.1.4 Mathematics

The other major tool needed for the evaluation of C^2 systems is a method of relating the inputs to a set of outputs that allows individual or comparative assessments. The working-group members defined two essential modeling dimensions. First, they developed a probabilistic formulation which reflects uncertainty and tests for model completeness. Second, they formulated mathematical components integrating the measures of C^2 dimensions, effectiveness, and force effectiveness.

3.2 What Do We Still Need?

The architecture we are proposing is not a complete structure. It is a framework to provide specific direction. The way to progress is to accept some structure that has been developed within the profession, test it, and iterate it. For example, operational models of the C^2 process should be constructed. Other parts of the C^2 system model remain to be developed or synthesized. Perhaps the many good-to-excellent models available for specific purposes might be incorporated into a generic model.

However, we are not now sufficiently advanced to provide this level of sophistication. We have identified some of the issues that relate to such an approach and some of the areas where progress is being made. Many more blanks remain to be filled.*

We are proposing to use the structure being established to generate additional analytical blocks. In this way, different techniques may be incorporated into an architecture for the evaluation of C^2 systems.

*A few of these have been filled even while we wrote this report. Specifically, Chapter 8 indicates the evolutionary nature of our conceptualization of the evaluation structure about which this chapter reports the June 1985 version.

This architectural strawman must be applied to real-world problems. The applications must be assessed. If they provide realistic solutions, this approach will be validated. If the architecture is productive for these applications, we should test the limits. If not, we need to determine why, and where it needs to be modified. Only if these findings are exchanged within the community will we continue to build on what has been established and accepted.

The exchange of experiences has already begun with respect to the theory of a generic conceptual model. Claims have been made that no general model is needed. Do we need an explicit generic model when we can work the parts? Do we need a theory of measures of effectiveness when we work specific analyses? Yet, more and more frequently, the demand is made to relate specific analyses to general force effectiveness. In essence, there is growing demand for an explicit generic model. Reality tells us that for any specific study we haven't time to develop a generic model as defined here. Even if it were developed, that model would be used modularly.

The architecture is designed to ensure that evaluation of C^2 systems is based upon appropriate factors. The architecture should be used for comparative evaluation of alternative systems and to assess individual systems. The impact of the system on other components of the model, e.g., organizations, processes, time, and space, can then be determined.

The characteristics we use today, e.g., technical and schedule uncertainty, effectiveness, impact on communications and other resources, will certainly be included. Further, new variables will be added relating to total force effectiveness, arms control, and technological progress. Finally, sensitivity analysis may be used to estimate the ranges of conditions and to determine bounds of uncertainties.

The architecture will expand as concepts are refined. A set of tools will be developed. These tools will allow the analyst and the decisionmaker to specify the problem quickly and succinctly, and then to proceed with the work of answering the specific questions involved in evaluating C^2 systems.

3.3 Existing Building Blocks

Despite a number of remaining unresolved areas, the Workshop can look with pride at several significant accomplishments. First, the structure we've called the architecture for the evaluation of C^2 systems has been made explicit. Often, prior work has been guided intuitively in determining the pieces for the required analysis, but without a suitable integrating structure. Moreover, we've firmly tied the "evaluation" effort to the specific decisions that need to be made, i.e., to the application area which the analysis is designed to support. These decision requirements establish the boundaries of the model and the scope of the analysis. In addition, the nature of the C^2 system was specified. A frequently overlooked major component, the C^2 process, was conceptually modeled.

Two opposing views of the need for a generic model have surfaced. Whenever the requirement is to determine the force effectiveness gain attributable to a C^2 system, an inclusive generic model is applicable. In contrast, other analyses focus on the subdivisions of the generic model, and more commonly smaller special-purpose models developed for each problem. This behavior results in the assertion that a generic model may not be needed.

The measures selected were tailored to suit the applications and the analytical model(s). The results of the analysis then more explicitly reflect the decisionmaking needs.

Finally, the mathematics were designed to accommodate a variety of possible models to enable formulation without restriction on the model contents. This effort resulted in a flexible and generic mathematical framework for the evaluation of C^2 systems.

3.4 Concluding Remarks

The existing foundations of this effort were established by decisionmakers and analysts at this and prior Workshops and Symposia. We have developed a broad structure for evaluation, but existing and new studies must be integrated. We must not view current inconsistency as indicative of lack of progress. Only through an architectural approach to evaluation will the full potential of C^2 systems be realized. In order to obtain maximum operational effectiveness, the capability must be understood. And in order to comprehend both the objective and subjective aspects, it must be subjected to an evaluation procedure that provides the breadth needed to include all its disparate parts.

CHAPTER 4

APPLICATIONS AND THE NEED FOR C^2 MEASURES

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4.0 INTRODUCTION

The objective of this chapter is to discuss applications of the C^2 measures and process model to the analysis of C^2 systems or to analysis of larger systems in which C^2 systems may be imbedded. Referring to the progress in this regard, Mr. Charles Zraket stated at the 1984 Symposium at The MITRE Corporation:

> "We have still not succeeded in formulating either an analytic methodology or a systematic evaluation process to deal with the two-sided dynamics of C^2 in warfare in contrast to analyzing, e.g., strategic force exchanges with static drawdown curves."

The key element in the quoted lament is the absence of a systematic evaluation process. Measures* are successfully used every day but in an ad hoc manner. This obstacle that has prevented the complete success of previous attempts at application of measures must be overcome.

The thesis of this report is that measures have wide application in both conceptual and implementation areas (categories) involved in the design, acquisition, and operations of C^2 systems.

*The term "measures," used throughout Chapter 4, refers to areas in which Measures of Performance or Measures or Effectiveness might be used.

Measures must be determined through an analytic effort that is as quantitative in its approach as possible. However, the extent of potential quantifications is a function of the nature of the applications. On the one hand, the formulation of budgetary POM decisions, decisions related to system design, the acquisition process, operational concerns, or more conceptual applications, e.g., assessment of new technology, development of R&D goals, and the determination of C^2 contribution to force effectiveness, are likely to show greater quantification. On the other hand, the development of doctrine or generating or validating requirements is likely to be more qualitative. Careful review is needed to ensure the appropriate level of quantification and to identify areas of potential bias.

The extent of objectivity will be evident if the purpose of the analysis is set forth. The supporting analytical model must be succinctly described. Data collection must be consistent with the model and be performed under specified conditions. To the extent possible, measurements should be repeatable. The translation of model inputs into measures of the C^2 system which are amenable to validation should be transparent for the decisionmaker and traceable for the analyst. The applicability of capability assessment, tradeoff analysis, and risk analysis to the conceptual and implementation categories must be determined in the analysis.

4.1 Chapter Organization

This chapter contains descriptions of the appropriate application of C^2 measures for analysis in conceptual and implementation categories, defined below. The following sections set forth application considerations based upon the nature of the C^2 system, the environment in which the system must operate, the interrelationship of this system with other systems, and other special aspects that affect its development or operation.

Section 4.2 defines the application categories and subcategories. Analytical implications of these applications are identified in Section 4.3. Guidelines for application of measures to specific categories are set forth in Section 4.4. Examples of applications are given in Section 4.5 and Section 4.6 presents conclusions and recommendations of the working group.

4.2 Pertinent Areas for Application of C^2 Measures

There are many areas of analysis in which C^2 measures can be, or should be, incorporated. These range from the analysis of C^2 equipment, in which the C^2 measures may be the only effectiveness or performance gauges, to the analysis of forces engaged in battle, in which C^2 measures are but one of many different measures used to determine force effectiveness. MOEs and MOFEs are related to both the operational context and the boundary of the C^2 system. These are derived from the analysis objectives. It seems likely that different sets of generic measures are required for different applications.

Since the scope of analysis in which C^2 measures should be applied varies greatly, it is useful to derive a set of broad analysis categories. These categories can then be used to determine how best to apply C^2 measures. The collection of analysis categories which follows has been organized into two distinct subcategories: those that address the conceptual examination and those concerned with the implementation of C^2 capabilities. Further, this section provides specific guidelines regarding the types of measures needed for each application category. Using Table 4-1 as the framework, some of the special requirements and considerations for measures that apply to each of the application categories are discussed.

TABLE 4-1

ELEMENTS OF APPLICATION

APPLICATION AREA	TYPE OF ANALYSIS	ANALYST'S ELEMENTS DECOMPOSITION	DECISIONMAKER
Conceptual			
Doctrine Development	TA, RA	Objectives (Nat'l, etc.) Strategy Mission	DOD, JCS, SVC Chief, Deputy Secretary
Requirements Generation/Validation	TA, RA, CA	Mission Existing Capability Functions	Gen. SVC Chief, Force Level Valid. JCS, SVC Chief, Force Level
C^2 Contribution to Force Effectiveness	TA, RA, CA	Mission Objective Mission Elements	Force Commander
New Technology Assessment	TA, RA, CA	Potential Capability Mission Function	System Command, Product Division
R&D Goals	TA, RA, CA	Mission Function	DOD, Deputy Secretary, System Command, Product Division
Implementation			
POM/Budget Process	TA, RA	Mission Area Program Element Project	DOD, Deputy Secretary, SVC Chief, Force Commander, System Command
Acquisition Process	TA, RA, CA	Program/System Project Mission Function	SVC Chief, System Command/ Product Division, Program Manager
Technical Evaluation	TA, RA, CA	System Subsystem Component	System Command, Program Manager, System Analyst, OT&E Command
Operational Evaluation	TA, RA, CA	Mission Function Task	Force Commander, System Command, System Analyst

Legend
TA = Tradeoff Analysis
RA = Risk Analysis
CA = Capability Assessment

4.2.1 Conceptual Category

The conceptual category includes those areas involving the formulation of concepts or doctrine, and those areas relating to the planning required to achieve future capabilities, including force requirements and force objective capabilities. The applications in this category begin at the higher level of doctrine development, but also subsume the generation and validation of requirements for C^2 systems and the evaluation of the contribution these systems make to force effectiveness. This very important aspect of force and system evaluation is the most difficult to quantify and places a heavy burden on the mathematical formulation and modeling. However, it also provides a basis for assessing both promising new technology and research and development.

4.2.1.1 Doctrine Development. These analyses examine ideas from the grand strategy level to the major military and naval commands. For example, the Air-Land Battle concept becomes doctrine through the use of idea generation, subjective analysis, models, simulations, war games, and military exercises. C^2 measures are not often directly addressed in the models and simulation portions of such analyses, but are frequently included in the more narrowly focused supporting models and simulations. Subjective analyses, war games, and military exercises should include C^2 measures, although they will often not be quantifiable.

Doctrine alternatives are normally evaluated by commanders and operations analysts. Evaluation of doctrine alternatives should be based upon tradeoff and risk analyses. In these analyses, both MOEs and MOFEs are required. The same set of MOEs/MOFEs must apply to all alternative doctrines. The selected set must reflect the condidate doctrine with respect to its function (mission) within the operational environment. As a minimum, the doctrine must be related to force effectiveness and be generic.

4.2.1.2 Requirements Generation and Validation Process. The Military Services and the Unified and Specified Commands have formal procedures to generate and validate requirements. These result from the official recognition that some new capability is or will be needed. An approval authority will validate the requirement that a new capability is needed. C^2 measures are frequently needed to analyze stated requirements and to assist in their clarification and validation. Several examples may be shown. For example, C^2 measures may be used to produce the specifics of a new requirement. Credible analyses, generated from postulated future enemy capabilities or from hierarchically structured C^2 measures, also can be used in deriving specific C^2 requirements from much broader objectives statements. C^2 measures are appropriate to verify that a new requirement exists.

The generation and validation of operational requirements for C^2 systems normally involve the decisionmakers listed in Table 4-1, subordinate commanders, and analysts. Engineers are usually restricted to technical consultation. Alternative requirements at the mission and function levels are evaluated using tradeoff analysis, risk analysis, and capability assessment.

Hierarchically structured MOEs and MOFEs show the force effectiveness impacts of each alternative requirements level. The requirements establish (1) minimum acceptable values for the MOPs, (2) subsequent verification of meeting the requirements, and (3) comparison with existing/programmed capabilities to identify shortfalls.

In evaluating systems with respect to requirements, credit should be given for exceeding a requirement by viewing it as a lower bound.

4.2.1.3 Evaluation of C^2 Contribution to Force Effectiveness. The development of a C^2 measure to determine the contribution of C^2 to force effectiveness is urgently needed. Joint and combined forces may be effective either through deterrence of combat or through success in combat. Robustness of C^2 is intuitively a strong factor in deterrence. C^2 analysis measures should demonstrate the contribution of C^2 to the avoidance of war.

The contribution of C^2 to force effectiveness or to success in combat may be analyzed with respect to small forces, or to joint and combined forces. The force effectiveness of a small ground force supported by close air support having a variable communications capability with the forward air controller would require both C^2 measures and weapons effectiveness measures. For larger forces, such as combined forces on a theater battlefield, C^2 measures, particularly those pertaining to command and control, should be applied to aggregate force capabilities.

C^2 contribution to force effectiveness must be determined using MOFEs whenever a "least-common denominator" is required for comparing disparate types of C^2 systems, e.g., a sensor system and a communications system. Since MOFEs are scenario dependent, system evaluation requires using several different scenarios. The specific values of MOFEs are largely subjective, so data from field exercises and military experience may be used to provide needed insights. For some applications, the MOFEs can be framed within a single military mission. However, when C^2 systems span several mission areas, they must be related to the ability to wage a particular type of war, representing the range of all pertinent missions.

4.2.1.4 New Technology Assessment. New technology assessment is performed by technical experts and analysts who determine the military ramifications of the projected technical capabilities. Tradeoff analysis, risk analysis, and capability assessment evaluate the relative merits of C^2 systems employing the new technologies to

those employing existing technology. MOFEs are required to evaluate the capability to conduct the applicable military mission using the proposed technologies. Technical risk will be a particularly important factor. MOPs reflecting the forecast technical capabilities will be related to the MOEs and MOFEs through a hierarchical structure.

4.2.1.5 Setting Research and Development Goals. The determination of which program to be pursued is closely related to both "new technology assessment" and "requirements generation and validation" conceptual application areas. Since alternative technologies compete for resources, C^2 measures are useful to illustrate either their absolute or relative values.

R&D goals, established to remedy identified operational shortfalls of present/programmed capabilities, are determined by operations analysts, systems engineers, and technical experts.

The shortfalls and alternative means of mitigating them are identified using tradeoff analysis, risk analysis, and capability assessment. MOEs will be required when goals must be prioritized, necessitating a common measure of the utility of disparate goals. MOPs must be related to required candidate system capabilities and the specific technical improvements.

4.2.2 Implementation Category

The implementation category is more quantifiable than the conceptual category. This category includes measures to assist in the development planning and tradeoffs of programs from early in the Program Objectives Memorandum (POM) and budget cycle through the acquisition process and into the technical and operational evaluation of these systems. There is a danger that the implementation category may be overemphasized, merely because it is more amenable to quantification and is less abstract in nature.

Attention must be paid to the structure of the system as well as the physical entities in this category to the extent possible.

The implementation phase begins by the selection of a program from a set of competing programs, each defined by a set of accepted requirements. Once a program is selected, the normal system development cycle is followed, namely: selection of a specific design, construction of an advanced development model and then an engineering development model, conduct of technical and operational evaluations of the engineering development model, and, if successful, implementation of full-scale production.

4.2.2.1 POM/Budget Cycle. All levels of the funds justification chain need applicable C^2 measures. At a very low level, i.e., at a base, a C^2 measure might be employed in analyzing the operational effectiveness improvement brought on by replacing an existing telephone switching system. At higher levels, e.g., Department of the Army, an application example of C^2 measures might be the investigation of the benefit of adding capabilities to satellite systems.

The evaluation of alternative programs for funding normally involves executives from the system commands as well as military commanders. System command executives could be analysts, scientists, or engineers. The merits of each program, the set of requirements each program fulfills, and its contribution to the effectiveness of the force which it is designed to support should be addressed by tradeoff analysis and risk analysis. MOEs and MOFEs are required for all candidate programs. If different capabilities as indicated by MOPs are shown with similar MOE/MOFE values, then additional MOEs should be developed.

4.2.2.2 Acquisition Process. Analyses supporting the acquisition process are focused upon design, development, production, and fielding/implementing of systems. Applicable C^2 measures include measures of hardware and software, and measures which reflect the

training, operational procedures, transition to new systems, and the introduction of new maintenance inventories. The effectiveness of C^2 systems critical to national security during transition is not a trivial problem. Another measurement requirement relates to including the "human-in-the-loop" aspects of C^2 in the analysis.

The objective of the acquisition process is to select one of the candidate system architectures/designs and carry it through to the mass-production phase. The evaluation of candidate architectures/designs of a specific C^2 system normally involves military commanders and program managers from system commands, engineers, analysts, scientists, and military commanders. Because of the pervasive nature of some C^2 capabilities, a large number of interfaces and interoperability considerations must be included in a valid analysis. Each alternative should be addressed with tradeoff analysis, risk analysis, and capability assessment in terms of one set of MOEs/MOFEs. Life-cycle costs and development-cycle time must also be emphasized. Requirements should be expressed in terms of minimum-acceptable values for each MOE. The selected MOPs and MOEs must be suitable for measuring the relative ability of the candidates to fulfill the requirements.

4.2.2.3 Technical Evaluation. Technical evaluation determines how well existing or developmental hardware/software systems meet their design criteria. Performance measures must be tailored to the C^2 system under investigation. For larger systems, of which C^2 is only one of several components, C^2 measures, measures of other system components, e.g., communications and weapons systems, and possibly a relationship from these measures to an overall system MOFE may be used.

The technical evaluation of a C^2 system will determine the degree to which a selected hardware configuration, e.g., the engineering development model, fulfills the specifications. It is normally conducted by the system developer under the supervision of

system command executives and the program manager. An Operational Test and Evaluation Command is normally represented.

Tradeoff analysis, risk analysis, and capability assessment will usually be needed to address alternatives for further development, testing, and operational implementation. The results of a technical evaluation should be expressed in the same measures adopted when selecting the system architecture/design.

4.2.2.4 Operational Evaluation. Operational analysis combines the technical evaluations with the organizational dimension. Thus, the analysis evaluates the ability of existing or developmental organizations, with their hardware/software, to meet the objectives for which they were created. The emphasis in these analyses is as much on the C^2 aspects as it is on communications.

Operational evaluation is usually performed as one of the last activities in the development phase before mass production of a C^2 system is allowed. Passing an operational evaluation is usually necessary for the acceptance of a system by the responsible Service.

The potential utility of the system is determined using tradeoff analysis, risk analysis, and capability assessment.

Force commanders, special test organizations unique to each Service, system command representatives, and system development agencies take part in the operational evaluation process.

MOFEs, MOEs, and MOPs are applicable to operational evaluation with emphasis on MOFEs, which are the primary output measures in this case. The MOFE/MOE/MOP set used in operational evaluation should be identical or at least closely analogous to those used in architecture/design selection and comprise a superset of those used in technical evaluation.

4.3 Application Considerations

This section outlines the analytical implications of each general application area for C^2 measures. These analytical

implications include: application and decomposition (or structure), bounding conditions and caveats, translation of needs and results between and among decisionmakers and analysts, differences in focus to account for current and future capabilities, and (5) observations about the practicalities of application. They are discussed for both conceptual and implementation applications.

The C^2 analysis approaches and techniques must (1) be tailored to the analysis objective, (2) consider alternatives and risk reduction, (3) take the system operational environment into account, and (4) include command structure and force employment options (orders of battle).

4.3.1 Application and Structure of Analysis

Table 4-1 indicates the type of analysis appropriate for each application area, together with the structure of analysis elements and the level at which decisions are made. These vary and are unique for conceptual as compared to implementation applications.

In the conceptual arena, which is largely mission-building/decomposition, for example, in doctrine development and objectives, e.g., national and Service level, are the starting point. Next, various levels of strategy to implement these objectives must be defined. Then missions and employment must be specified. Thereafter, Service doctrine must encompass these elements.

In implementation, the primary system is decomposed, doctrine is defined and goals are set. For example, in programming and planning the POM/budget, the analysis will likely start the decomposition at the mission area and then descend through program elements to programs or projects. This breakdown is useful to understand and support the building of the DOD (Service, Component) investment strategy.

It should be noted that the type of decisionmaker varies with the kind of application area. In the conceptual area, the decisionmaker/commander dominates the final decision with support from planners, programmers, and developers. In the implementation area, planners, programmers, and developers dominate decisionmaking in the planning and acquisition processes.

4.3.1.1 Analysis Versus Decisions. It is suggested that a decision-oriented analysis approach be taken. This approach must include:

a. Mission goals and objectives.

b. Decisions required to achieve the goals and objectives.

c. Information needed to make the required decisions. From this information, problem definition for analysis begins, leading to the solution of questions such as: (1) Do current capabilities satisfy the mission requirement? (2) Will programmed capabilities satisfy the mission requirement? (3) What modifications (process or system), new capabilities, or new technology are needed? (4) What operational alternatives are viable?

To develop a decision-oriented analysis approach, one must also focus on the intended use and the likely user. Thus information needs may be expanded to identify the information to decisionmaking and the information to be produced as a result of the decision outputs. Identifying information needs must be related to the decision level, which relates the required data to decisionmaker needs and is essential to achieve practical results to properly support decisionmaking. Table 4-2 portrays both the decisionmaker and user organizations based upon application area and analysis objectives.

4.3.1.2 Use of Analytical Tools. Three broad analytical tools are useful in these applications, namely, capability assessment, risk analysis, and tradeoff analysis. Within each application area, the analysis objective(s), the portrayal of results, and the level at

TABLE 4-2

RELATIONSHIP OF ANALYSIS TO DECISIONS

TYPE OF ANALYSIS DECISION	PURPOSE OF ANALYSIS (TO SUPPORT/INFLUENCE)	USER OF ANALYSIS RESULTS	USER ORGANIZATION
Conceptual (Operationally Oriented)	Develop Doctrine	Force Commander(s)	Services, Operational and Training Commands (e.g., TRADOC, Schools)
	Requirements Generation and Validation	Force Commanders, Development Agency Commanders, Force Employment Planners	Services, Operational Commands
	Evaluation of C^2 Contribution	Development Agency Commanders, Operational Commanders	Services, Operational Commands, Development Agencies
	Definition R&D Goals, Assess New Technology	Service Secretaries, Development Agency Commanders, R&D Executives, Operational Force Planners	Services, System Commanders, Laboratories, Operational Commands
Implementation			
- Programmatic	POM/Budget Deliberations - Cost vs. Capability - Cost vs. Schedule	Service Secretaries, Force Commanders, Acquisition Executives	DOD, Services, Operational Commands, System Commands
	Acquisition Decisions - Schedule - Cost - Capability	Development Agency Commanders, Acquisition Executives, Program/Project Managers	Services, System Commands
- Acquisition	Capability Definition - Facilities - Equipment - Technology Applications - Operational Concept	Acquisition Executives, Program/Project Managers, Force Employment Planners	System Commands, Operational Commands
	Support Needs - Facilities - Equipment - Personnel	Logistics Executives, Program/Project Managers, Force Employment Planners	System Commands, Logistics Commands, Operational Commands

which the decision is made must be well defined. These tools are related to their use, indicating special considerations in Table 4-3.

The same types of analysis are used in different application areas. However, the thrust of the analysis and the questions to be answered must be uniquely defined for each problem. Further, the approach must consider the information required by the decisionmaker for that application.

4.3.2 Practicalities of Application

For most efficient use, the analysis must be carefully structured, taking into account the realities of decisionmaking. Table 4-4 outlines practical considerations. The primary factors describe some of the bounding constraints of the analysis. The observations characterize the likely nature of the analysis, e.g., more qualitative than quantitative, as well as provide insight into capability, development, planning, and programming needs. It is stating the obvious to note that implementation work will tend to be more quantitative and better defined than conceptual work.

4.4 Examples of MOE Application

4.4.1 C^2 MOEs in the TACAMO Capability Analysis

Evolving technologies, both of the United States (U.S.) and the Union of Soviet Socialist Republics, led to the conclusion several years ago that a major program would have to be initiated by the late 1980s to increase the U.S. capability to command and control its undersea missile fleet. Preliminary analyses reduced the options for consideration to two--either to procure more C-130s, or to buy a replacement aircraft, the E-6.

The primary analytical requirement was to meet essential C^2 needs at a minimum total cost. The overall C^2 MOE was, in general terms, "How well does this system (either the C-130 or the E-6) meet the C^2 control criteria?" The C^2 requirement was expressed as the

TABLE 4-3

SELECTED APPLICATIONS VERSUS TOOLS
(CONSIDERATIONS)

Type of Tool	Application Area	Tool Use and Special Considerations
Capability Assessment	Conceptual	Force-Employment Oriented
	Implementation	Force-Element Oriented
Risk Analysis	Conceptual - Doctrine - Force Effectiveness	Focus on Strategy and Reaction - Identified vs. potential set - Must be able to define C^2 contribution
	- Requirements - R&D Goals - Technology Assessment	- Focus on potential payoff among alternatives (technical feasibility, right population of real need, etc.)
	Implementation	Cost, Schedule, Performance (needed/desired vs. achieved/achievable)
Tradeoff	Conceptual	Focus on alternative strategies and use of forces, requirement priorities, mission objectives, potential capabilities
	Implementation	Focus on cost effectiveness (utility)- must address logistics and manpower, funding profiles (stretch-out), performance (technical and operational), sensitivity to variations in these parameters

TABLE 4-4

PRACTICAL APPLICATION CONSIDERATIONS

Applications	Primary Factors	Observations
Conceptual		
Doctrine Development	Ranges from tactical force element (unit) to global force projection/employment. Typically top-down approach.	Must recognize C^2 system as supporting capability, not an end. More qualitative than quantitative.
Requirement Generation and Validation	Governed by doctrine, national objectives, defined strategy, existing/programmed capability, threat.	More qualitative than quantitative.
C^2 Contribution to Force	Need demarcation of force elements. Need defined force objectives.	Inadequate consideration of innovative methods vs. traditional--more and faster may not be better.
New Technology Assessment	Feasibility of development of new approaches from available technology.	Window of opportunity dependent. May be possible, but infeasible.
R&D Goals	Ability to forecast needs. Guidance on mission priorities.	Need to be longer range (at least 5-10-year windows). Priority weighting tends to be subjective.
Implementation		
POM/Budget	Annual quick-reaction process.	Funds constrained. Vested interest in current programs. Need to weigh resources required against differing capabilities.
Acquisition	POM/budget establishes resources. Requirements bound system development.	Technology applied must be in window of opportunity. Support (logistics and manpower) often treated inadequately. Operational concept is important. Mostly quantitative.
Technical Evaluation	Measure of hardware (system, subsystem, etc.) capability.	Need to clearly define objectives and distinguish from operational capability or effectiveness. Quantitative.
Operational Evaluation	How does the system (equipment, procedures, manpower) perform in the intended operational environment?	Need normal (intended) logistic support. Must use planned operational procedures.

need to provide an .xx probability of reaching yy% of the submarines in the required time. Soviet jamming power and nuclear bursts intended to disrupt C^2 were assumed. The driving parameters of the analysis were the strength of electronic signals emitted by the aircraft and aircraft location in relation to a geographically fixed array of submarines.

It is interesting to note that aircraft speed and endurance (time aircraft can remain aloft), which have nothing to do directly with communications, were actually C^2 MOPs by virtue of their relation to the overall C^2 MOEs. These factors drove the estimate of how many aircraft were required. MOPs more commonly understood as directly related to communications included communications equipment reliability, signal strength (including the power-generation capability aboard the aircraft), and message transmission/retransmission accuracy.

4.4.2 C^2 MOEs in Redeye Employment

The Digital Communications Terminal (DCT) was used in early 1978 as a C^2 device to assist the Redeye gunner in the employment of his weapon. The DCT was connected to the Tactical Air Operations Center, which provided air-traffic information. The Redeye gunner now had a display which provided a much-increased range for observation and indication of the type of aircraft, i.e., friendly or enemy.

Operational tests were conducted to determine if a gunner could effectively use the DCT and the information provided to engage targets successfully. In order to remove the gunner's inherent ability to observe and then engage a target, he was placed under a poncho, which limited his vision to only the DCT and Redeye displays. The gunner was required to observe the indications from the DCT, point his weapon in the proper direction indicated by the DCT to detect an ememy aircraft, and then once the weapon indicated acquisition of ~~the~~ aircraft, fire on the aircraft within the

engagement envelope of the missile. This activity was expected to be accomplished without any direct visual observation of the aircraft by the gunner.

The DCT provided a map display of the gunner's position and selected key terrain around his position. The Tactical Air Operations Center provided the location and classification of targets to the DCT for display on the map. The target information was provided in near real-time potentially sufficient for acquisition.

C^2 measures were applied to this test at two levels, with a third not considered. The first level was an MOP which considered the ability of the gunner to read and understand the data provided by the map to produce useful information for his mission. The second-level measure, an MOE, was the evaluation of the application of the information provided in successful engagement of targets. The third-level measure, an MOFE, not addressed during this test but important to employment of the system, was the contribution of the DCT to enhance the effectiveness of Redeye as a close-in air-defense system.

4.4.3 Selection of an Architecture for DOD Common-User Telecommunications

This example is taken from a recent effort to select the preferred alternative for the Worldwide Digital System Architecture (WWDSA). The purpose of the architecture was to serve as an overall "umbrella" for the development of all future DOD common-user telecommunications systems. The alternatives were developed by first establishing the user requirements and comparing them with the existing capability to determine needed improvements, and then postulating a set of significantly different architectures for providing the needed improvements. The selection process, which is the focus of this example, involved development of a hierarchical set of effectiveness and performance measures, along with a set of

measures reflecting the various types of implementation penalties, scoring the alternatives against each measure, and deciding which alternative is "best" in an overall sense.

The top-level measures are shown in Table 4-5. Note the basic dichotomy between "effectiveness," which measures all benefits expected to accrue from having a particular architectural alternative, and "implementation," which measures all penalties that must be paid for employing it.

Effectiveness was decomposed, at the next level, into four categories. "Capability" measures how well the system does its basic task of transferring information when the network is undamaged. "Survivability" measures the resistance of the system to sustaining damage from enemy attack, along with its ability to perform in a partially damaged state and its ability to restore some of its destroyed capabilities. "Adaptability" measures how well the system can respond to changing environmental conditions, e.g., its ability to extend its boundaries, reconfigure its connectivity, accommodate traffic peaks, and interoperate with other systems. "Security," which measures the integrity of the secure communications service, could logically have been placed under "Capability," which was subdivided to highlight this vital consideration.

No method presently exists for relating a common-user telecommunications system to force effectiveness, since the system serves a multiplicity of user types, both for primary and backup connectivity, and must be "all things to all people." Accordingly, the highest level of effectiveness reflected how well the system accomplished its basic job of moving information, without regard to how the receipt of this information might have an impact on force effectiveness. The development of a general method for measuring

TABLE 4-5

WWDSA TOP-LEVEL MEASURES

Effectiveness

- Capability
- Security
- Survivability
- Adaptability

Implementation

- Cost
  - Life Cycle Cost
    - R&D
    - Implementation
    - O&M
  - Manning
  - Spectrum
- Risk
  - Technical
  - Cost
  - Schedule, etc.
- Technical
- Cost
- Schedule
- Transitioning
  - Uniformity of Cost Profile
  - Continuity of Effectiveness

the contribution of common-user telecommunications systems to force effectiveness is an important challenge facing the C^2 community.

Table 4-6 shows the successive decomposition of the "Capability" category, as an illustration of the tree structure. Similar structures were developed for the other three effectiveness categories.

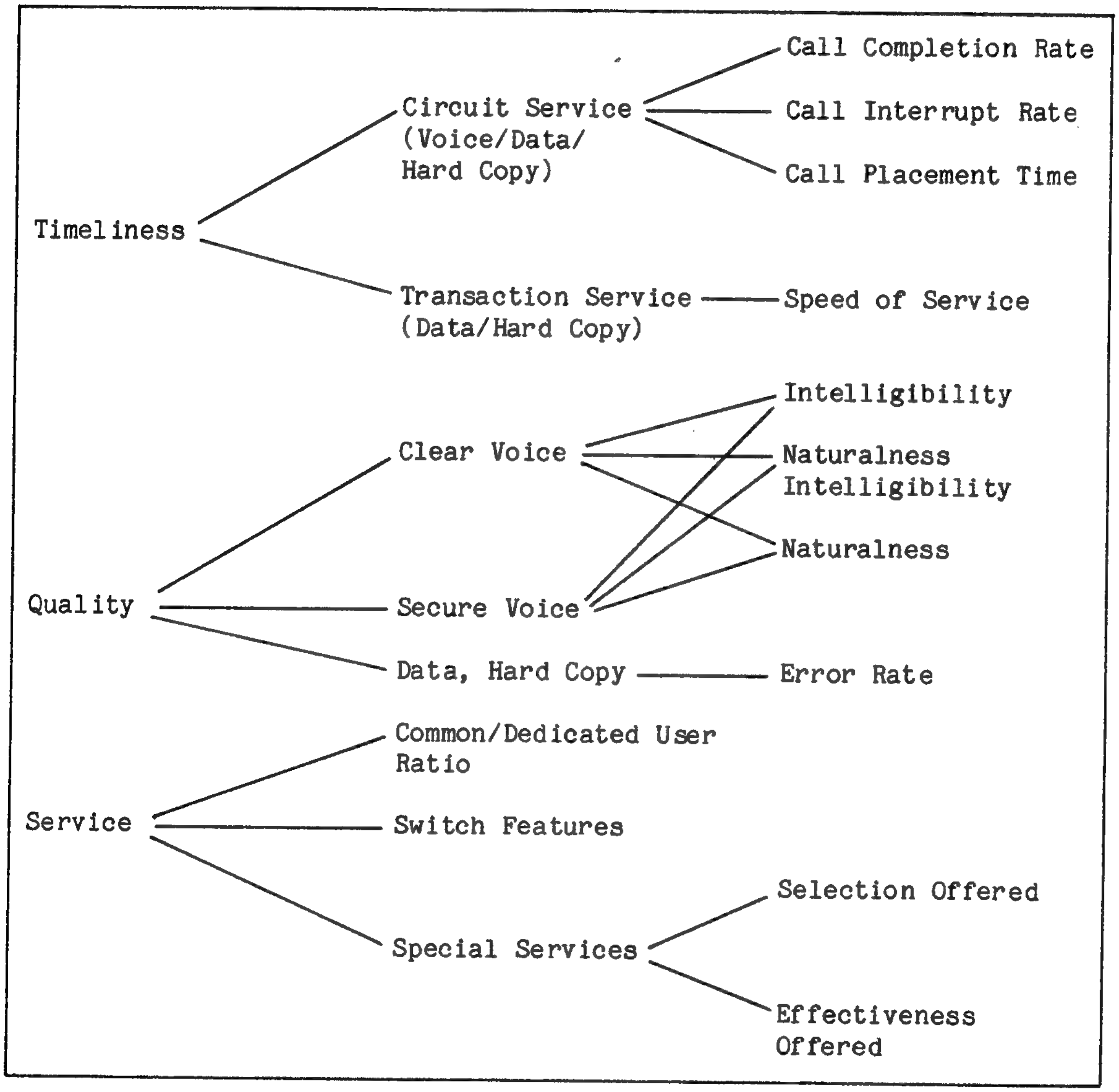
No further decomposition of "Implementation" was used beyond that shown in Table 4-5. "Cost" refers to all valuable resources that must be expended to realize an architecture, which accounts for the inclusion of manning and spectrum under this category. The three subdivisions under "Risk" pertain to uncertainties in being able to achieve the assumed values with respect to effectiveness, cost, and schedule, respectively. Finally, "Transitioning" refers to the relative ease with which the present systems can evolve into the architecture under evaluation, as measured by the flatness of the required funding profile and the lack of degradation in effectiveness during the transition period.

Explicit definitions were constructed for the lower level criteria in order to promote a common understanding of the quantities being scored. The criteria developed for WWDSA should be generally applicable for any common-user telecommunications system if modified as appropriate to highlight different design factors and to extend down to lower levels.

The scoring of alternatives against the measures was conducted by a team of experts collectively knowledgeable in all aspects of the problem. The scores were expressed in terms of relative utility and were assigned initially at the bottom level of the tree. These scores were propagated to the top level of effectiveness through the assignment of importance weights by means of a multiattribute utility model. The Effectiveness scores were plotted against the Implementation scores to show dominance of alternatives and the

TABLE 4-6

DECOMPOSITION OF "CAPABILITY"



"knee of the curve." These scores were also combined through the use of relative weights to yield an overall "figure of merit." Numerous sensitivity excursions were made through computerization of the scoring process.

The decisionmakers were pleased with the results and felt confident that the best alternative had, in fact, been selected.

4.5 Conclusions and Recommendations

In this chapter, the application of MOEs based upon the analysis objectives has been addressed. The specification of MOEs is treated in other chapters. After the the perusal of these chapters, the reader may have a better view of both the availability and adequacy of tools for evaluating C^2 systems.

An important aspect of OE application is the clear delineation of the caveats related to the formulation and use of these measures. The process must be as objective as possible and perspective must be maintained so that it can be recognized if the model, the analysis, or the MOE applies to the C^2 system being addressed. As MOEs are applied to the areas addressed in this chapter (including considerations (Section 4.3) and guidelines (Section 4.4)), the adequacy of the MOEs as a tool must be assessed and fed into the process.

4.5.1 MOE Application - The Process

As a process, the formulation of MOEs is recursive and iterative. As illustrated in Table 4-1, the determination of shortfalls in MOEs applied to a C^2 system is fed back into the conceptual model so that this model can be modified, refined, or changed. Over time, the MOEs can become accurate measures of an existing system or can be modified to cope with evolutionary changes in the system, the environment, or the scenario.

4.5.2 Realities of the Process

The application of MOEs must be reviewed as a process in order to ascertain the fidelity of results to reality. Some aspects of this determination have been discussed above. The review should answer questions similar to the following:

a. Do the MOEs appear to match the system being evaluated? Do these measures derive from an appropriate model? Is the data consistent? If surprises exist, can they be explained?

b. Was the data accurate, reliable, and relevant? Does it appear sufficiently complete to apply the MOEs?

c. In collecting and assembling data, were the methods of data reduction, the standards against which they were measured, and the method of dealing with "gaps" or "holes" acceptable and credible?

d. How was the data reduced? How much information or dimensionality was lost in the data collection and reduction processes?

e. Were subjective techniques, if used, based on sound judgment? Were they sufficiently explained to justify their contribution to the analysis? Was their relevance to the conclusions affected by these techniques?

f. Looking at the analysis, to what changes in parameters are the conclusions and findings sensitive? Is the sensitivity analysis relevant and credible?

g. From the viewpoint of the C^2 system program manager, designer, or operator, how significant are the conclusions and findings derived from the application of the MOEs? Have we verified what we already know (status quo), or does this analysis contribute to programmatic, design, or operational decisions?

4.5.3 "Selling" the Analysis

If MOEs are expected to be useful, they must be accepted by decisionmakers. For a considerable length of time, results of MOEs derived for the analysis of C^2 systems have failed to convince

decisionmakers, whether they are operational commanders, commanders of system commands, DOD officials, or members of the Executive Branch, e.g., Office of Management and Budget, or the Congress. Care must be taken to apply principles successfully used to "market" systems and to relate MOE analysis to the capability of C^2 systems. Transparent models and simple MOEs are helpful. However, the character and characteristics of the audience must be considered in preparing presentations, briefings, or reports. When subjective techniques or judgments are necessary during the analysis, they should be considered frankly and honestly. If "soft" areas appear in the data or the analysis, the conclusions should identify a caveat so that the integrity and credibility are discernible to the audience. A coherent story line should extend from assumptions through the analysis to the conclusions. Finally, conclusions should be clearly linked to the analysis presented.

CHAPTER 5

MODEL

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5.0 INTRODUCTION

This chapter introduces and develops the conceptual model of a C^2 process and relates it to C^2 systems for the purpose of measuring various system designs. Also presented is an explicit description of the process with a discussion of how it can be applied to analyzing C^2 systems.

5.1 Background

Chapter 2 provides the definition of C^2 and extends it to introduce the concept of C^2 systems as well as the C^2 process. The distinction between these two concepts is that the C^2 system represents the physical entities and the structure of what is needed to perform C^2, while the C^2 process represents the C^2 functions of how C^2 is performed.

Most military analysts have an intuitive understanding of these concepts and how they relate to their C^2 systems. However, there is not sufficient agreement on any general model of the "what" and "how" of these systems for purposes of comparative analysis and, ultimately, decisions about their procurement and use. The reasons for this lack of consensus are many but they can generally be reduced to three. First, most analysts believe that the uniqueness of each Service's role and mission defies generalization. Second, they also believe that C^2 is so complex that each analysis requires

a fresh and unique approach depending upon the system and situation being evaluated. Finally, the results of all analyses are usually special purpose.

Consequently, models are not readily communicated among different users or adaptable for other purposes, e.g., results of analyses for procurement of systems may not be applicable to evaluation of doctrine. Accordingly, a fundamental representation of the processes inherent in any C^2 system must account for these concerns if it is expected to be useful as a tool for communicating across a wide variety of analytic concerns.

5.2 Requirements for the Model

The following requirements must be met if a conceptual C^2 process model is to be considered complete:

a. The model must be understood and agreed to by all types of users for both conceptual and implementation applications.

b. The model must represent all the functions addressed by a C^2 system as well as serve as the basic building block for analysis of individual process components of the C^2 system.

c. The model must have the ability to clearly define the boundary of the C^2 system by differentiating between C^2 components and non-C^2 force components.

d. The model must allow for representation of time and organization among and within individual C^2 entities.

e. The model must provide the ability to represent the internal dynamics of the C^2 system, such as iterative and reflexive (short-circuited) processes described below, as well as the interactions of the C^2 system with the environment.

f. The model must provide the framework for measuring the C^2 system at three levels, in particular, MOPs, MOEs, and MOFEs.

g. The model must consider human decisionmakers from the standpoint of cognitive processing factors.

h. The model must provide the ability to represent information transfer.

5.3 Assumptions

To develop a model that satisfies the above requirements, it is necessary to make several assumptions:

a. A definable, fundamental C^2 process exists that comprehensively describes the functional aspects of the system.

b. This process is a functional description equally applicable to the simplest and the most complex systems.

c. This process or combinations of this process can be analyzed in context, provided a goal statement and environment can be articulated.

5.4 C^2 Process Model

This section presents the basic model and demonstrates its ability to be combined to provide a hierarchical representation of military C^2 structure. Also described is the applicability of the model to a conventional timeline analysis. Next, the techniques are extended to a two-sided model which is representative of C^2 in a Red/Blue engagement. The model is then subjected to a simplified timeline analysis. Finally, the model is applied to C^2 superordinate and subordinate systems.

5.4.1 The Basic Model

The primary intent of the Conceptual Model working group was to provide a basic model that, in its most simple form, represents the basic constituents of the most simple C^2 process and yet can be extended to the most complex system. The basic model is shown in Figure 5-1. As shown, there are two interactions with the environment. These interactions are represented by a stimulus input and a response output. The output can only cause an action through our own forces, which results in a change to the overall

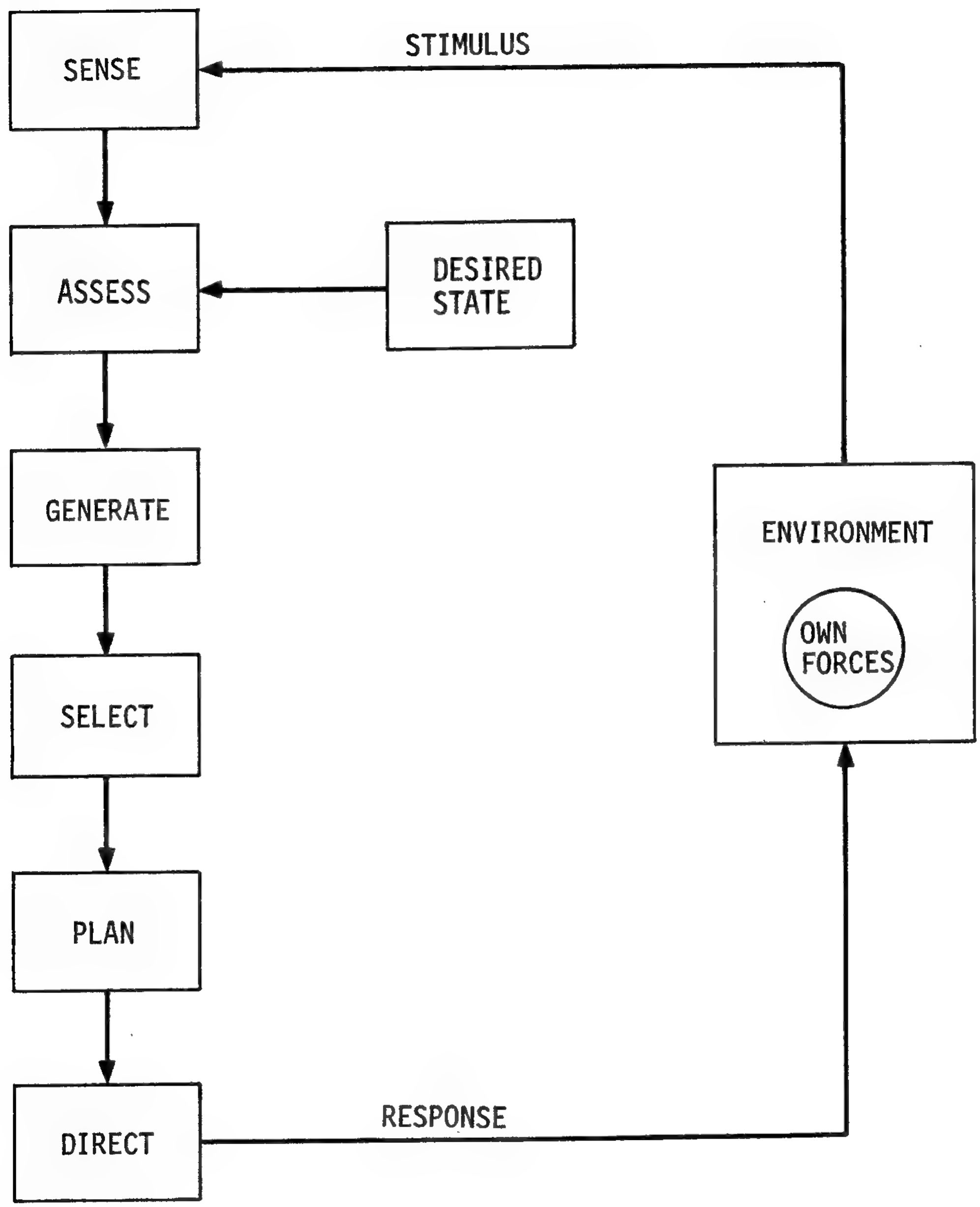

FIGURE 5-1
CONCEPTUAL C^2 PROCESS MODEL

environment. External inputs are shown coming from the environment and are susceptible to both natural and human-initiated environmental effects. The only other direct input to the process, the Desired State, establishes an error function inside the loop. This error function causes processing activity to continue, or, at the other extreme, halts processing activity when the Desired State is believed to be reached.

Definitions of individual functional boxes in the loop are presented below. The loop process is initiated when a sensed input is assessed and is determined or is believed to be in error with a Desired State or when our requirements for the Desired State change. These errors cause the generation and selection of options, which result in a plan intended to change the environment. The objective is to minimize the difference between the assessed and desired environment.

5.4.1.1 Definition of Functions. This section provides definitions of the functional blocks of the C^2 process model shown in Figure 5-1:

a. Sense - That function which collects data necessary to describe and forecast the environment, which includes:

   1. The enemy forces' disposition and actions.

   2. The friendly forces' disposition.

   3. Those aspects of the environment that are common to both forces, e.g., weather, terrain, and neutrals.

b. Assess - That function which transforms data from the Sense function into information about intentions and capabilities of enemy forces and about capabilities of friendly forces for the purpose of determining if deviation from the Desired State warrants further action.

c. Generate - That function which develops alternative courses of action to correct deviations from the Desired State.

d. Select - That function which selects a preferred alternative from among the available options. It includes evaluation of each option in terms of criteria necessary to achieve the Desired State.

e. Plan - That function which develops implementation details necessary to execute the selected course of action.

f. Direct - That function which distributes decisions to the forces charged with execution of the decision.

5.4.1.2 Implicit Considerations in the Structure of the Conceptual Model. The basic model has a very simple form, with all of the functions performed sequentially by the conceptual C^2 system. A real system, however, may execute the functions in a distributed way, and substantial interactions may exist among sets of C^2 systems in the performance of the functions. Further, a given system may, at times, appear to omit some of the functions or have loops within the model that allow the execution of the basic functions in a different order.

These apparent variations can actually be accommodated within the conceptual model. However, some of the functions may be performed implicitly. For example, a reflex action may appear to be produced by the simpler model shown in Figure 5-2.

All the functions in the process are actually performed, though some may not be consciously recognized. A reflex action that directs an action from sensed data, for example, results from a previously learned response. That is, the system that performs reflexively has learned to execute the process in a way that implicitly and rapidly:

a. Assesses the situation.

b. Generates the alternatives.

c. Selects the appropriate alternative.

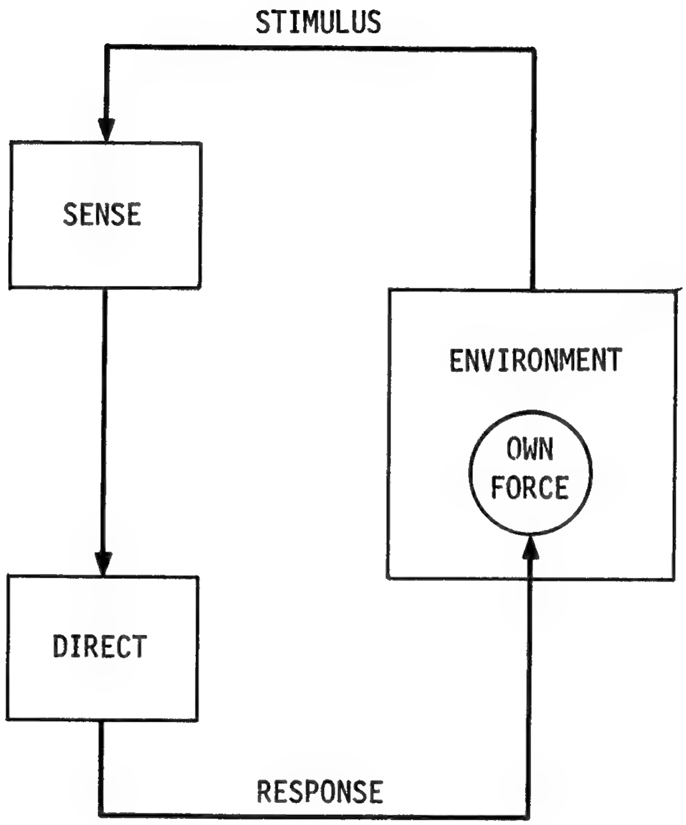

FIGURE 5-2
SIMPLER REFLEX FORM OF CONCEPTUAL C2 PROCESS MODEL

The conceptual model can also be applied to more complex systems in which the process is executed in a distributed way or where multiple systems interact. These applications are discussed in the following paragraphs.

5.4.2 Application of Model to Hierarchical Systems

Multiple C^2 entities (Figure 5-3) can be represented with combinations of the fundamental process. This example shows the coordination of two subordinate entities operating within a shared environment. C^2 entities expanded to represent these nodes are also shown in Figure 5-4. Layered coordination functions are depicted to illustrate the multiple simultaneous functions that can occur independently within nodes of the same system, e.g., two brigades are connected to a third. Coordinating directives are provided as a Desired State condition input to the Assess function of the independently directed elements. This Desired State condition is the output of the Direct function of the coordinating element.

It is significant to note that this is a functional representation and that in a physical system the Desired State may arrive from the environment via the Sense function. Also implied is the premise that physical limitations may cause distribution of functions. Application of the model in this way represents the hierarchical relationship within a command structure. The model can apply equally well to the coordination of activities between parallel nodes, where, for a specific situation, one of the nodes may "coordinate."

A similar structure can also describe the interactions of different processes within a single node. Adaptive radar and communication systems, for example, will require processing within the Sense function to distinguish and validate (Assess) communications messages and environmental situations, e.g., must be able to differentiate among targets and communications.

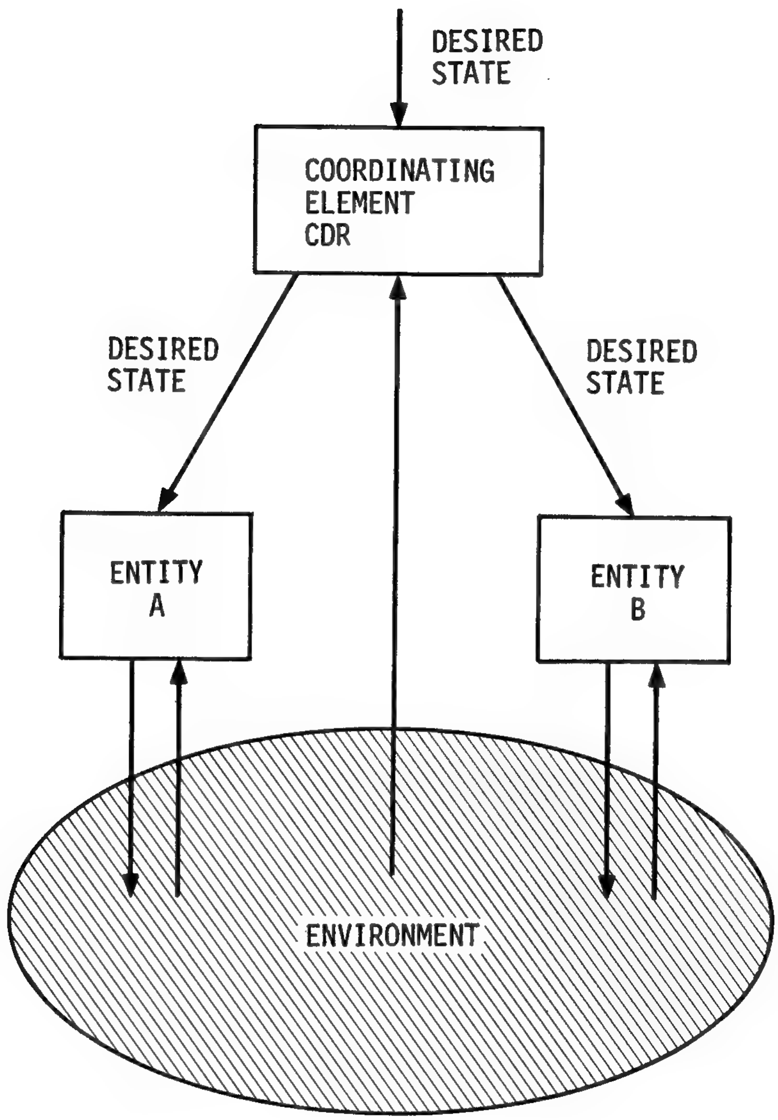

FIGURE 5-3
COORDINATION OF MULTIPLE C^2 ENTITIES

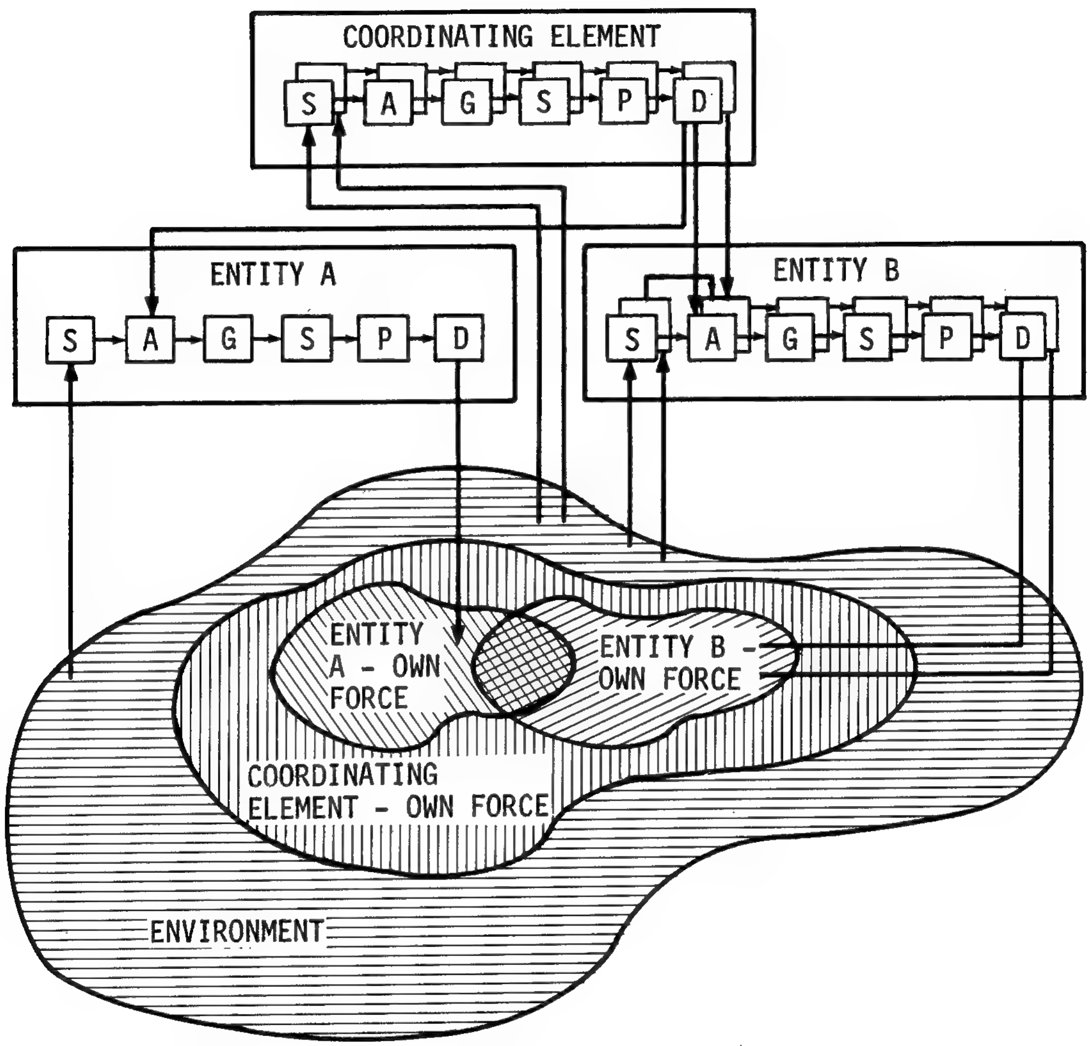

FIGURE 5-4
C^2 ENTITIES EXPANDED TO PROVIDE COOPERATION AMONG INDEPENDENT C^2 NODES

5.4.3 Two-Sided Model

Because the definition of the basic functions within the conceptual model does not specify the methods that will be used to accomplish the functions, the structure of the conceptual model for interactions between two opposing systems is very similar to the model for two cooperating systems. A schematic of the former is shown in Figure 5-5. As with the cooperating systems, the primary interactions between the two are accomplished through the environment, though the interactions are somewhat indirect, i.e., there is no direct communication of the Desired State from one of the systems to the other, and each desires to create a different environment.

The principal differences between the interactions of opposing versus cooperating systems would be (1) the relationship between the Desired States (what is good for one side is bad for the other), (b) the treatment of uncertainties in assessment, and (c) the specific details of the approaches used to generate systems and select the course of action.

5.4.4 Consideration of Time

The conceptual model does not explicitly represent time. The timing and sequencing of the execution of the functions by a C^2 system, however, are major characteristics of the system. Examination of the timeline characteristic of the system has long been recognized as important, especially under circumstances in which the functions are performed by distributed systems. This type of analysis is especially important for the common situations for which the Desired State is time dependent or it is assessed that the deviation of the actual situation from the Desired State is time related.

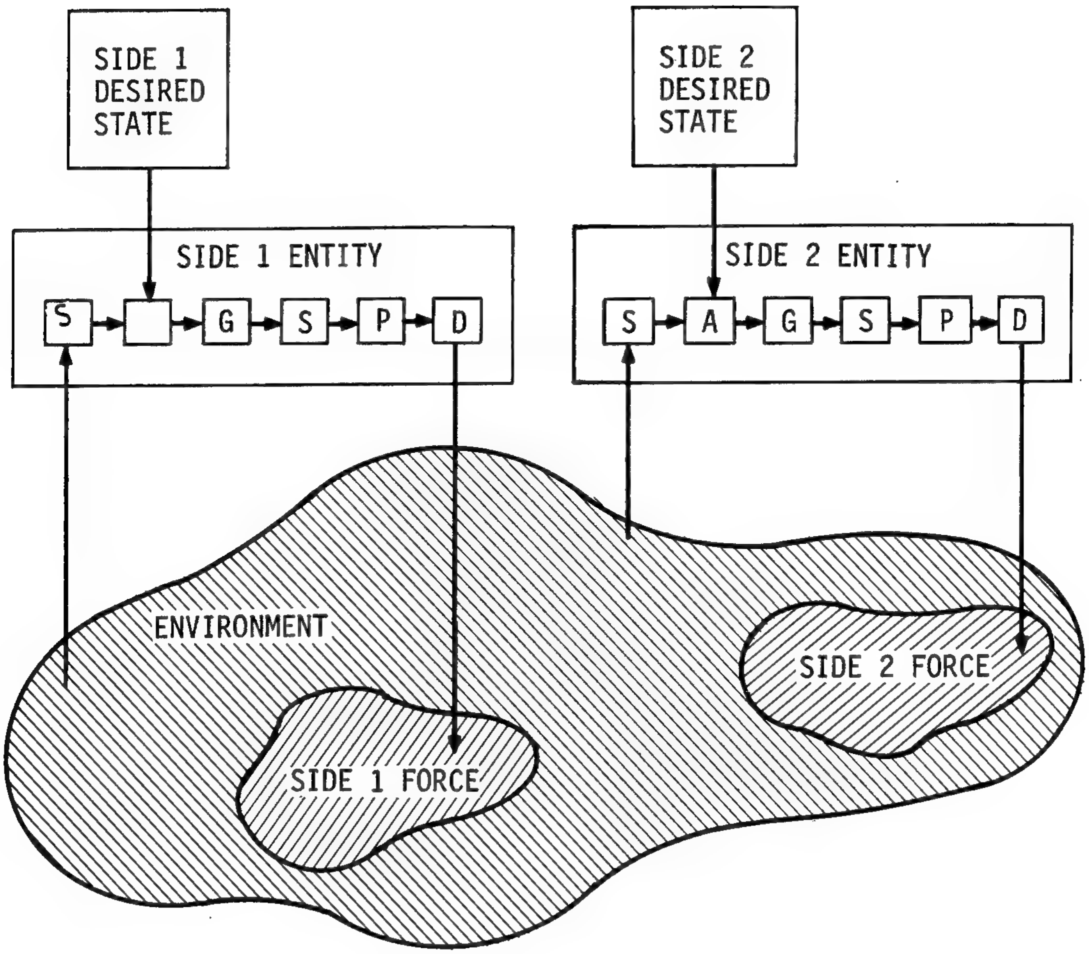

FIGURE 5-5
TWO-SIDED MODEL

An example of the relationship between the functions of the C^2 process and a timeline is demonstrated in Figure 5-6. A fundamental requirement of a C^2 system is its ability to effect a desired change in the environment within an induced timeline before other changes nullify the desired change. For example, if "destruction of enemy aircraft at their bases" is a Desired State, then the C^2 system could be deemed ineffective for the particular task if the time required to perform the C^2 functions and execute the selected course of action exceeds the time remaining before enemy aircraft are launched from their bases.

The modeling of the performance of the C^2 functions by a distributed system on a timeline becomes extremely complex. The use of a timeline model, however, can help in sorting out the complexities and allocating priorities for further development of the capabilities of the system to execute the functions. Figure 5-7 provides an example of a schematic timeline model of a distributed system with three specialized components: a commander, an analyst, and a sensor. Each of the components could be modeled as a "system." For example, a radar "sensor" performs all of the functions in the C^2 process in order to accomplish its sensing mission. In a higher level system, however, the components could be viewed as specializing in the performance of one or more of the functions, and some portions of the functions may be executed in parallel. The commander and the analyst, for example, may begin to assess while the sensor is still sensing. Additional time can be saved for the activities in support to each of the functions by performing some of the activities in parallel. The incremental value of any changes in the way that the system performs the C^2 functions can then be evaluated in terms of the effects on the overall timeline of the entire system.

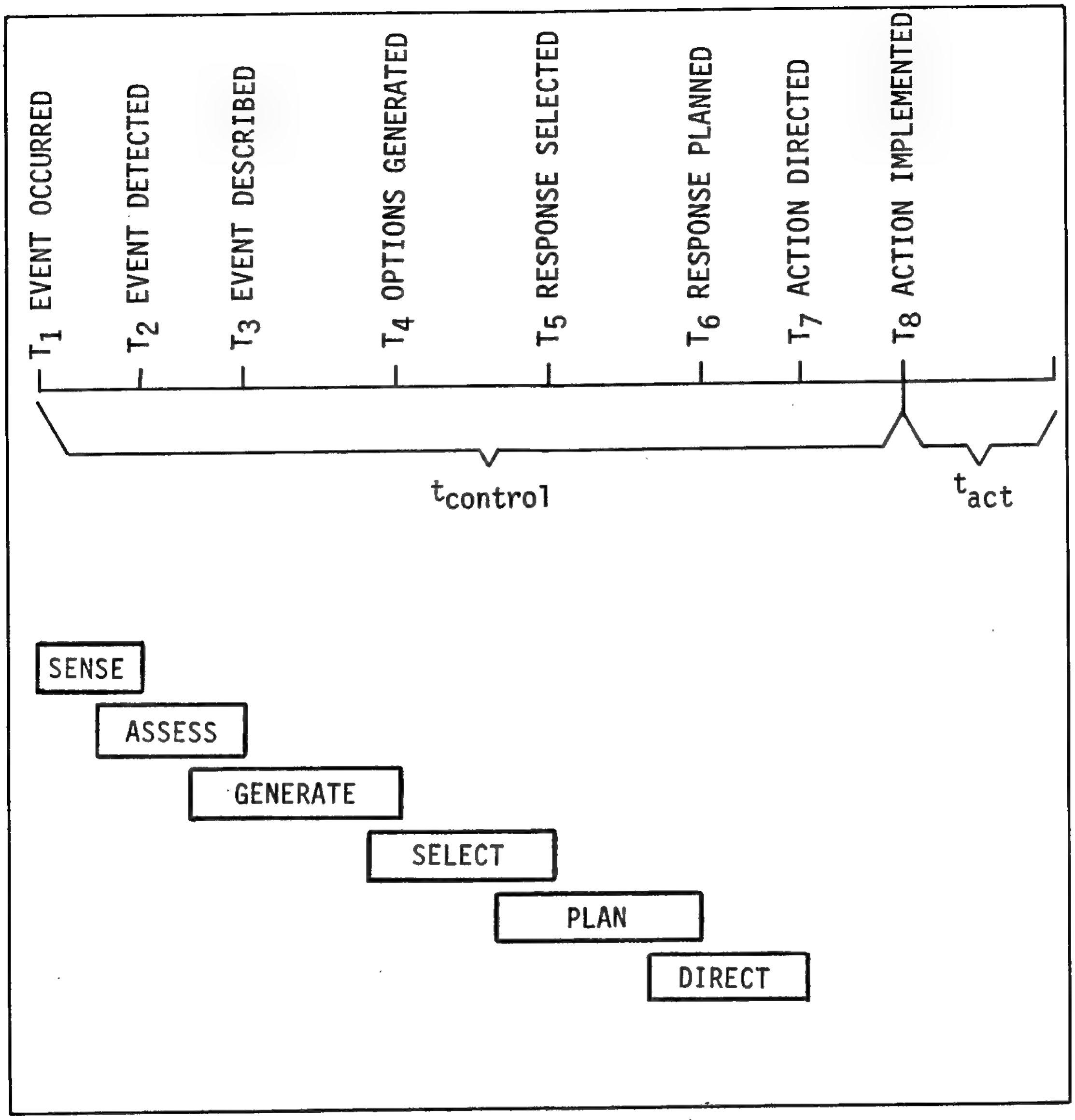

FIGURE 5-6
CONCEPTUAL C2 TIMELINE

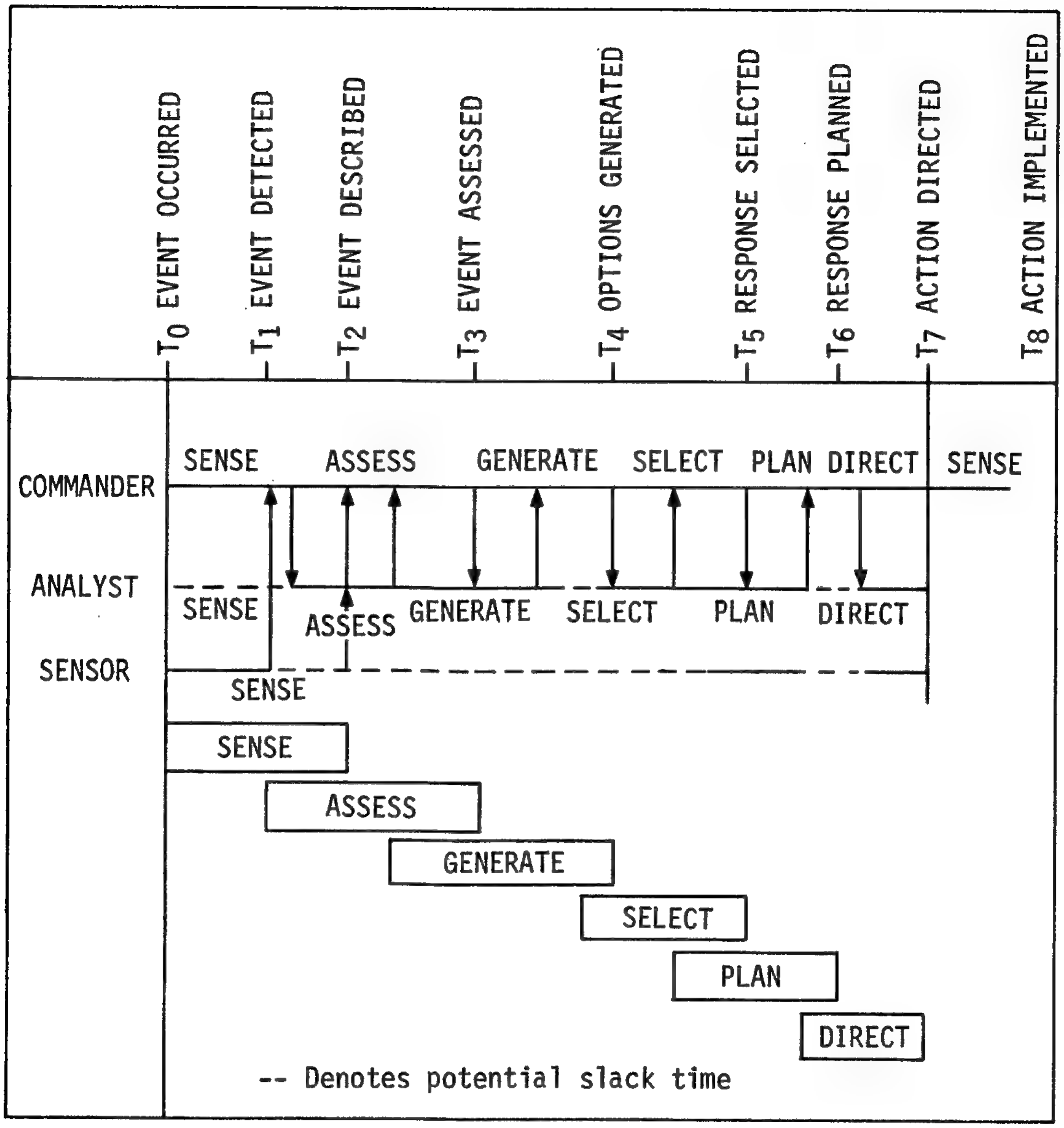

FIGURE 5-7
C^2 TIMELINE FOR A MULTIPLE-COMPONENT SYSTEM

5.4.5 Application to the C^2 System

As stated in the previous section, the conceptual model was shown to be applicable to more complex systems. In that section, a hierarchical system was presented which can be extended to a more complex form required to represent military C^2 structures. This is possible by emphasizing certain characteristics of these structures; namely, they:

a. Contain several parallel paths with similar subordinate structures.

b. Require extensive coordination between parallel entities.

A simplified application of the conceptual model to a representative military subordinate C^2 problem is shown in Figure 5-8. For decision purposes, the Desired State of the separate entities of the system is set with the transmission of the Air Tasking Order (ATO). The separate subordinate activities contained in the parallel structure have responsibility for detecting and launching attack aircraft to engage detected enemy aircraft. The stimulus to the Air Display Unit results in sensed enemy aircraft and a directed response which flows horizontally to the operations center. This response now becomes the stimulus to the Sense functional component of the aircraft operations center process, resulting in a response causing launch of aircraft. This launch now causes the change in the overall air situation environment.

The same basic reasoning will allow treatment of superordinate C^2 structuring. As before, the Desired State is established by the transmission of the ATO. The engagement process covered in the above section is still valid. The sensed activity/response takes place until the Desired State is achieved. At this point, the results of the subordinates in achieving the Desired State are reported in terms of response to the superordinate level.

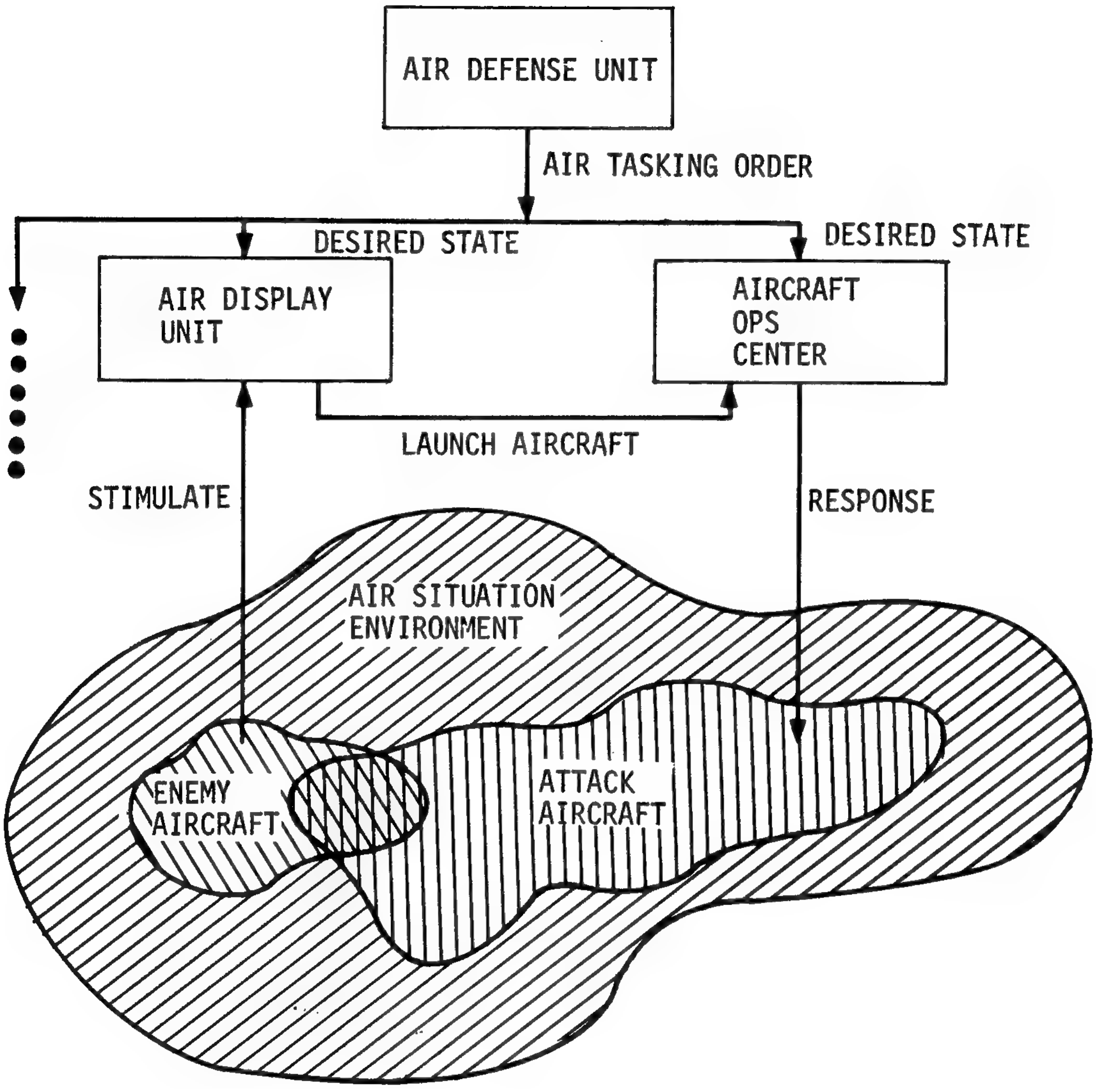

FIGURE 5-8
SUBORDINATE AND SUPERORDINATE MODEL APPLICATIONS

5.5 Measuring C^2 Systems Using the Process Model

The C^2 process model can be used to clarify the part of the C^2 system that needs to be evaluated as well as to relate the three types of measures introduced in Chapter 2 to the process model.

5.6 Selecting the C^2 System

All Services now have C^2 systems that extend from the Commander-in-Chief to the junior rifleman, airman, or seaman. However, it is not necessary to consider the entirety of these systems in all evaluations. Instead, most analyses need to focus on only selected portions of these systems. To borrow from Enthoven and Smith, "How Much is Enough?" is the principle when selecting a portion of the C^2 systems for analysis. For example, when studying the Army's Firefighter* system, how much of the total C^2 systems must be included to sufficiently answer questions regarding the performance of Firefinder, relative to the performance of the entire fire support system and of the force as a whole?

The C^2 process model can assist in defining the portion of the total system that needs to be analyzed in the following manner. First, Firefinder performs a Sense function for the C^2 system. If measures are to be used only to describe the technical performance or details of the Firefinder system or to compare them to known capabilities of like systems, then no other entity of the C^2 system need be included. However, if it is desired to ascertain how Firefinder contributes to the overall fire support system, then the C^2 entities that perform the Assess, Generate, Select, Plan, and Direct functions associated with Firefinder must also be included as part of the C^2 system. In this particular example the functions relating to positioning the system in a tactical environment as well

*Counterbattery/countermortar radar.

as transferring its sensor output into firing commands for particular weapons systems should be included.

It should be clear that an analyst can use this approach as a guide and a check to see if that portion of the C^2 system being evaluated is necessary and sufficient to answer the questions.

5.7 C^2 Measures

In Chapter 2, the concept of three levels of measurement for C^2 were introduced. This concept is readily extended to the C^2 process model developed above.

First, MOPs are used to measure how well a particular function of the C^2 process model is performed. Reverting to the Firefinder example presented earlier, MOPs would be used to describe how well Firefinder Senses, e.g., detection range, location accuracy, speed of service.

Second, MOEs measure the integration of all C^2 functions of the process model. Again referring to the Firefinder example, any C^2 measure of effectiveness must include not only the Sense function but its interaction with the other five functions as they relate to the selected C^2 system. For example, one measure of how well counterbattery fire is commanded is "the time from enemy fire of an artillery piece until an order is given for counterfire." This measure includes, of course, not only how accurate and fast the Firefinder system determines and detects the enemy firing location, but also how this target data is Assessed in terms of threat and value to the force mission, how options are Generated to respond to the enemy fire (artillery or air strike) and Selected, Planned (fire order or close air support strike is prepared) and Directed (fragmentary order issued).

Finally, MOFEs relate the C^2 system to the force, including weapons capability. A measure of the time from enemy firing of an

artillery piece to the silencing of that piece would be an MOFE. The appropriateness, completion, and timeliness of any such action are further examples. For example, in the Firefinder paradigm, any C^2 system that only generates air strikes in response to enemy artillery fire would generally yield untimely and inappropriate responses to squelch that fire because delays in aircraft arrival are usually long unless the aircraft was loitering in the area.

5.8 Summary

In summary, we have discussed the assumptions and requirements necessary for a fundamental representation of a generic C^2 process model. Working from these requirements, the C^2 process model is defined to consist of a sequential arrangement of the six functions: Sense, Assess, Generate, Select, Plan, and Direct. These functions operate upon and within a defined environment. Action within the process loop is initiated by a perceived divergence from a Desired State and a sensed environmental state.

The C^2 process model was subjected to experiential checking during the working-group deliberations. The checking was designed to exhibit the model's adaptive properties, while maintaining its fundamental structure. These checks indicate that the model allows for the representation of multidimensional processes interacting internally and through the environment.

Simple timeline analysis examples demonstrated the ability to expand or collapse the model functionally while maintaining desired time sequencing.

5.9 Strengths/Weaknesses

Significant strengths derive directly from the simplicity of the model and its elementary properties. C^2 processes can be easily visualized as an ordered arrangement of the functional blocks. These ordered arrangements lend themselves to mathematical

modeling. Complex systems may be selectively decomposed using a window approach and constructs of the basic elements.

The use of lumped functional qualities within the basic model will not completely describe a distributed process system. The group did not attempt dynamic representation of such a system; however, discussion indicates that a time sequence stop-frame approach may be fruitful.

Open questions remain concerning positioning the functional blocks of the model within the environment and determining the exact entry point for the Desired State stimulus.

CHAPTER 6

MEASURES

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6.0 INTRODUCTION

Previous chapters have developed a framework for the analysis of C^2 systems. The current chapter addresses the analysis process, focusing on the specification and selection of measures of performance and effectiveness.

6.1 The Analysis Process

In any analysis supporting decisions during the life cycle of a system, it is essential to be able to relate the contribution of the various alternatives under consideration to the desired objectives of the system, or military force. The mechanism by which this relationship is established is referred to as the "analysis process." While there is no single universally accepted structure that defines this process, it is generally agreed to involve a set of activities similar to those identified in Figure 6-1 and listed below:

a. Problem Formulation involves the development of a clear, well-defined statement of the issue or question. As a result, appropriate analysis objectives and assumptions are identified, and the criteria for selecting preferred solutions are selected. These criteria are the measures of performance and effectiveness previously defined in Chapter 2.

b. Search involves the identification and selection of a set of alternative solutions to be evaluated, as well as the means to develop the information needed to conduct a

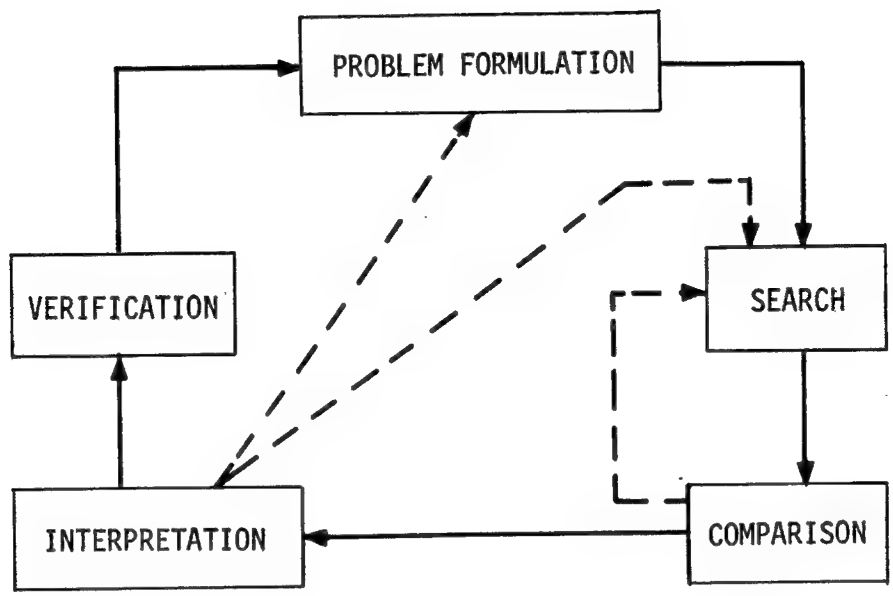

FIGURE 6-1
THE ANALYSIS PROCESS

comparison of those alternatives. The means alluded to here generally refers to mathematical models, simulations, war games, experiments or tests, and their associated input data requirements.

c. Comparison involves the rank ordering of the alternatives under consideration on the basis of the criteria (MOP and MOE/MOFE) identified during problem formulation.

d. Interpretation involves assessing the results of the analysis in terms of the objectives previously selected. It draws on the information and insights developed thus far by the analyst, and frequently requires the use of judgment and intuition. Interpretation usually results in conclusions and, in some instances, proposed courses of action. As indicated in Figure 6-1, interpretation can (and frequently does) result in looping back to some previous point in the process, e.g., to Search, to refine some aspect of that analysis, such as re-defining some alternative on the basis of insights developed during the comparison phase of the analysis.

e. Verification. Ideally one would always like to verify the results (interpretations) of an analysis. Unfortunately, particularly in military analysis, this is seldom possible, especially during the early stages of the system life cycle. As an alternative to verification, analysts and decisionmakers must generally be content with quality assurance that relies heavily on peer review and similar assessments of the logic, models, and data employed in an analysis.

The proper selection of the criteria to be used in comparing alternatives is one of the most important steps in developing an analysis plan. Furthermore, the ability (or inability) to specify the values of those criteria will eventually influence the efficacy of the analysis to accomplish the objectives defined during problem formulation. Currently, the criteria selection process is more an art than a science, and may always be so. A major objective of this report, however, is to establish a common basis for a more structured approach to this selection process. Accordingly, the major focus of the remainder of this chapter will be on the selection and specification of the system and force-level

measurement criteria, the MOPs, MOEs, and MOFEs defined in Chapter 2.

6.2 C^2 Systems Analysis

The previous section provided a general discussion of the analysis process and the role of measures (criteria) selection and specification in that process. This section will focus specifically on the analysis of C^2 systems. The goal of this section is to develop further the relationship between analysis measures and the means by which those measures are specified, and the purpose and objectives of the analysis. At any point during the life of a system, certain issues are of particular concern to system designers, resource managers, and/or users. These issues determine the objectives and focus (or scope) of the analysis, which in turn directly influence the selection of appropriate measures to be used and ultimately the means of specifying those measures.

6.2.1 System Life Cycle

The life cycle of a C^2 system has traditionally been segmented into three phases: concept definition, acquisition, and operation. The objectives of each life-cycle phase are described below.

6.2.1.1 Concept Definition Phase. Develop the total system and program requirements from a broad system or mission objective. The requirements can then be used to support the technical and management decisions regarding development of the system. During the concept definition phase, the system effectiveness analysis is used to develop and define a cost-effective system that will satisfy the operational mission. The characteristics of the system that most affect mission objectives are identified. Implications of tradeoffs between the desired system characteristics and other constraints are determined so that realistic goals for the characteristics can be set.

6.2.1.2 Acquisition Phase. Accomplish detailed engineering designs. The system is built and tested to determine whether or not the system and its subsystems meet specifications. Engineering reviews and test programs are conducted to determine contractor compliance with the specifications.

6.2.1.3 Operation Phase. Install the system and operate and test the system in a realistic operational environment. Assess the capability of the system to meet the effectiveness requirements originally defined in the concept definition phase. During the operation, system effectiveness measures may be used to reconfigure and manage an operational system in real time in order to optimize resources to maximize the system's effectiveness or performance.

6.2.2 Types of Analyses

Depending on the nature of the issues, or objectives of the analysis, the scope, or focus, of that analysis may be at the subsystem, system, or mission level.

6.2.2.1 Subsystem Analyses. Subsystem analyses are limited to some element, or component, of the C^2 system of interest. An example of such an analysis would be an evaluation of the performance of radar operating as part of a larger air-defense C^2 system. The inputs to such an analysis are dimensional parameters. The output criteria used in the comparison of such an analysis are called MOPs.

6.2.2.2 System Analyses. System analyses involve assessments of the C^2 system. Depending on the scope of the analysis, the inputs may be subsystem dimensional parameters (in the case of very detailed studies) or subsystem MOPs (in more aggregate studies). In any event, the output measures are system MOEs.

6.2.2.3 Mission Analyses. Mission analyses are designed to address the contribution of the C^2 system to the military force of which it is a part. Mission analyses may be used to determine the C^2

system's required operational capabilities for the force to accomplish its assigned mission. Also, mission analyses may be used to measure the contribution the system makes to force missions. The inputs to such an analysis may be subsystem-dimensional parameters or MOPs, or system MOPs or MOEs, depending on the detail required. The output measures employed are mission-MOEs or MOFEs.

6.2.3 Selection of Measures

As previously mentioned, the phase of the life cycle, the analytic objectives, and the analytic focus combine to determine the measures to be used and the means, i.e., models, to include tests and war games, to be employed in specifying those measures. Tables 6-1, 6-2, and 6-3 illustrate these relationships in considerably more detail. Each table addresses a type of analysis: mission, system, or subsystem. For each type of analysis, sample measures and model scope are related to analysis objectives and phases of the life cycle. Model scope, which addressed the means by which measures are specified, is designed to summarize the extent to which certain variables, e.g., forces, environment, alternative descriptions, tactics, should be represented within those means.

6.2.3.1 Table 6-1 (Mission Analysis). The measures for mission analysis are usually MOFEs. The measures chosen must provide a quantitative value to the effects of the C^2 system upon the ability of the force/C^2 system to carry out its mission. Thus the types of measures chosen for mission analysis are directly related to the outcome or force status during and at the culmination of the particular scenario chosen to test the C^2 system.

The measures can be very generic, such as, "Did the U.S. win, lose, or draw?" But the measures could be more specific, such as number of targets destroyed by each side or force status of each side during and after the scenario.

TABLE 6-1

OBJECTIVES, MODELS, AND SAMPLE MEASURES FOR C^2 MISSION ANALYSIS

LIFE-CYCLE PHASE	ISSUE		
	OBJECTIVE	MODEL SCOPE	SAMPLE MEASURES
Concept Definition	Determine the desirable force C^2 system characteristics. Develop a general definition and desired C^2 system capability.	Broad, interactive, general	Outcomes - win, lose, draw Status vs. Time (U.S. vs. Enemy) - Force C^2 capability - No. deliverable/commandable weapons - No. targets destroyed - Timeliness of responses - Ability to respond apropriately
Acquisition	Determine if the C^2 system as designed supports the desired force/C^2 system capability.	Broad, interactive, much detail, especially in C^2 area	Same as above
Operational	Evaluate the operational C^2 system capability to achieve desired outcomes for particular scenarios.	Broad, interactive, very detailed (including use of actual systems)	Same as above

TABLE 6-2

OBJECTIVES, MODELS, AND SAMPLE MEASURES FOR C^2 SYSTEM ANALYSIS

LIFE-CYCLE PHASE	ISSUE: OBJECTIVE	ISSUE: MODEL SCOPE	ISSUE: SAMPLE MEASURES
Concept Definition	Determine the required C^2 system characteristics, determine current system capabilities, deficiencies, and select "best" of alternative system definitions	System, some threat, closed loop, general to fairly detailed	- Survivability/endurance - Types of information available - Timeliness of data - Decision response time
Acquisition	Determine "best" design; test and evaluate developmental system	System, threat, environment, open and closed loop, much detail	- For sensors, accuracy/ timeliness of displayed information - For communictions, capacity, number channels - For command centers, display refresh time, ease of comprehension of information
Operational	Evaluate the operational C^2 system to determine if its performance meets the specifications or requirements	System, simulated threat and environment, open and closed loop, much detail	Same as above

TABLE 6-3

OBJECTIVES, MODELS, AND SAMPLE MEASURES FOR C^2 SUBSYSTEM ANALYSIS

LIFE-CYCLE PHASE	ISSUE		
	OBJECTIVE	MODEL SCOPE	SAMPLE MEASURES
Concept Definition	Determine the required C^2 subsystem characteristics, determine current subsystem capabilities, deficiencies, and select "best" of alternative subsystem definitions	Subsystem, some threat, open loop, general to detailed	- Survivability/endurance - Accuracy - Timeliness - Capacity
Acquisition	Determine "best" design; test and evaluate developmental subsystem	Subsystem, threat and environment, open and closed loop, much detail	Sensor - Resolution, sample time, sensitivity, power-aperture or number pixels Comm. - Bandwidth, frequencies, bit error rate Processing and Display - Number ops per second - Display cycle time - Availability
Operational	Evaluate the operational C^2 subsystem to determine if its performance meets the specifications or requirements	Subsystem, simulated threat and environment, open and closed loop, much detail	Same as above

The scope of the model for performing a mission analysis must be broad, that is, it must have a representation of all or many of the components of the friendly and enemy force/C^2 structures, including environmental and threat effects, tactics, and different strategies. The different components must be interactive so that the effects of each friendly or enemy system or tactic can be determined in a quantitative manner.

In the concept definition phase, the model can be very general, that is, representative of a system but not very detailed. In the acquisition or operation phases, the model should be quite realistic and hence very detailed in its complexity.

6.2.3.2 Tables 6-2 and 6-3 (System and Subsystem Analyses). The best measures for system or subsystem analyses may be MOEs or MOPs respectively. The measures chosen must provide a quantitative value for the ability of a particular system or subsystem to meet specifications or reasonable performance standards. The types of measures chosen must indicate the quality of the system's performance to the decisionmaker.

The measures can be somewhat general, such as the survivability of the system, or very specific, such as the probability of detection for a sensor system or the reliability of a sensor subsystem component.

For the concept definition phase, a model capable of closed-loop operation is required. Closed loop means that the model can interact with other factors, such as support systems, enemy threat, environmental effects, and the forces. However, these other factors need not be represented in detail since we are only attempting to determine the principal characteristics of the system being considered for development.

However, during the acquisition and operation phases, the model must be very representative (that is, very detailed in its complexity) of the actual system when the actual system is not used for testing. The system can be tested in an open loop (for verifying that the system can meet engineering specifications) and in a closed loop (for verifying that the system is effective in its mission context). The input data for closed-loop operation is much more complex than for open-loop operation because other systems, friendly and enemy, threat, and environment, are usually included. This is especially true for general war exercises at the major command level.

6.2.3.3 Analysis Utility. The objective of any analysis is to ascertain quantitative values for the particular measures chosen to evaluate a system. The values will then be used by the decisionmaker for decisions regarding the system.

The analyst who is charged with performing an analysis to provide a decisionmaker with information concerning a particular C^2 mission, system, or subsystem must be aware of the life-cycle phase and the type of analysis desired. Using Tables 6-1, 6-2, or 6-3, the analyst can arrive at the expected complexity of the analysis.

These tables list some sample measures to illustrate the focus required for the various categories of analysis. Obviously no such list could be exhaustive in the sense of identifying appropriate measures for every possible C^2 analysis. Therefore, it is advantageous to have a set of guidelines to assist analysts and decisionmakers in the selection of MOPs, MOEs, and MOFEs. Such a set of criteria is presented and discussed in the next section.

6.3 Characteristics of Measures

Performance and effectiveness measures can be characterized by their physical and analytic attributes.

Physical attributes involve the functional category to which the measure belongs, its name, dimensional units, and numerical value. To illustrate the physical attributes of a measure, consider a communications system as an example. While there is no universally accepted procedure for functionalizing communications system measures, one frequently used method is to subdivide them into four categories: communications measures, stability measures, reorganization measures, and security measures. An example of a specific measure within the communications category might be "speed of service," whereas a useful stability measure might be the "system availability." The system "speed of service" could be measured in terms of its "expected time to transmit a message," and specified in units of time.

Analytic attributes are desirable characteristics that can serve as a useful guide to analysts in selecting appropriate measures. The following table (Table 6-4) provides a list of such desirable characteristics. The first four of the characteristics described (mission oriented, discriminatory, measurable, and quantitative) are particularly critical to successful analysis, and will be addressed in further detail in the subsequent discussion.

6.3.1 Key Characteristics

6.3.1.1 Mission Oriented. Effectiveness measures are, by definition, mission oriented. The measure selected should be related to a clearly defined statement of the mission, or objective, of the system, or force, under consideration. This statement provides explicit or implicit information regarding the standards involved. As an example, let us consider an analysis involving an

TABLE 6-4

DESIRED CRITERIA FOR MEASURES

CHARACTERISTICS	DEFINITION
Mission Oriented	Relate to force/system mission.
Discriminatory	Identify real differences between alternatives.
Measurable	Able to be computed or estimated.
Quantitative	Able to be assigned numbers or ranked.
Realistic	Relate realistically to the C^2 system and associated uncertainties.
Objective	Defined or derived, independent of subjective opinion. (It is recognized that some measures cannot be objectively defined.)
Appropriate	Relate to acceptable standards and analysis objectives.
Sensitive	Reflect changes in system variables.
Inclusive	Reflect those standards required by the analysis objectives.
Independent	Mutually exclusive with respect to other measures.
Simple	Easily understood by the user.

acquisition radar that is part of an air-defense C^2 system. An objective (or mission) of this particular radar is to acquire targets in the shortest possible time, given that line of sight exists between the radar and the target. The performance of the radar might be expressed in terms of range, power, cycle time, discrimination, and frequency, for example, whereas effectiveness is expressed in terms of the radar's mission. Under these circumstances, a useful effectiveness measure for a radar evaluation would be the "time to detect the target given the existence of line of sight." Of course, the radar may have other missions, and in that case other measures should be selected for each of those tasks.

6.3.1.2 Discriminatory. Measures must discriminate sufficiently so that real differences among alternatives can be readily identified. Without this measurement capability, important information can be obscured. For example, consider a comparison of two competing air-defense C^2 systems, e.g., one manual, the other automated. The role of the C^2 system in the air-defense mission is to provide direction to the forces. A "better" C^2 system will result in "better" air defense, in some sense when a proper measure is chosen, e.g., number of friendly fighters lost versus enemy fighters shot down. However, regardless of the control model (manual or automated) employed, there might be very little variation observed in "number of friendly fighters lost." Does this mean that automated control is no better than manual control? Not necessarily. The problem may very well be that the selected measure was simply not sufficiently sensitive to distinguish between the two control systems. For that matter, unless friendly losses to enemy air attack were suspected to be a significant portion of total number of friendly fighters lost, major changes in said losses due to improving the air-defense C^2 system should not be expected a priori. An effectiveness measure, however, that might be more discriminating in this case is "friendly losses to enemy air attack."

6.3.1.3 Measurable. A measure must represent a measurable concept. Data collection must be possible. As a general rule, "values" are assigned to measures on the basis of observations acquired through the use of a broad range of analytic tools. These include, but may not be limited to, historical files, experiments, field-training exercises, war games, combat, mathematical models, and computer simulations. The scenarios and combat models are discussed in more detail in the following section. However, it should be noted here that certain combinations of scenarios and analytic tools may preclude (or certainly severely limit) the opportunities to acquire the data necessary to quantify a measure. In a field-training exercise, for example, the inability to position "observers" in a particular location may deny the analyst access to the data needed to assign values to a specific measure.

When computer simulations are used as analytic tools, certain combat functions required to quantify measures may simply not be represented at all or in adequate detail. Finally, when conducting experimentally based evaluations, the appropriate instrumentation must be available.

6.3.1.4 Quantitative. It is preferable for ease in analysis that measures be quantifiable. For example, a numerical undimensional measure facilitates both the (univariate) ranking of alternatives and the (multivariate) combination of measures. The process by which the measures are "combined" is generally made easier (but certainly not trivial) if the "values" of the various measures can be specified as numerical quantities. It is necessary that both the numerical values and the nature of the relationships between measures be specified. For example, how are time and accuracy related? Is the equation or set of equations linking a set of measures additive, multiplicative, or of some other functional relationships?

6.4 Specification of Measures

This subsection contains a discussion of two approaches to assigning values to measures of performance/effectiveness.

An approach to the specification of measures that focuses on their hierarchical relationship is illustrated in Section 6.5.

Once the type of analysis (mission, system, or subsystem) has been selected for the life-cycle phase of interest and the desired measures of performance/effectiveness have been determined, the general approaches to determining the values of the measures for the system of interest are either to use a model of the system of interest with the proper input data or, if the system exists, operate the actual system versus simulated data and conditions.

6.4.1 Analysis Using System Models

System models are either analytic models (closed-form mathematical equations) or simulation models. The models can vary from a back-of-the-envelope description of the physics of the problem to very large, complex, and detailed simulations that include many and varied systems/subsystems, environmental effects, forces (both friendly and enemy), and procedures. The model should produce values for those variables required to compute the selected measures, and be constructed to the desired detail and accuracy required for the decision regarding the system being studied.

An illustration of a generalized system simulation model is shown in Figure 6-2. The input consists of data for initial C^2 system parameters (system performance characteristics, system survivability/endurance characteristics, and strategy and tactics) and scenario data (environmental characteristics, enemy system

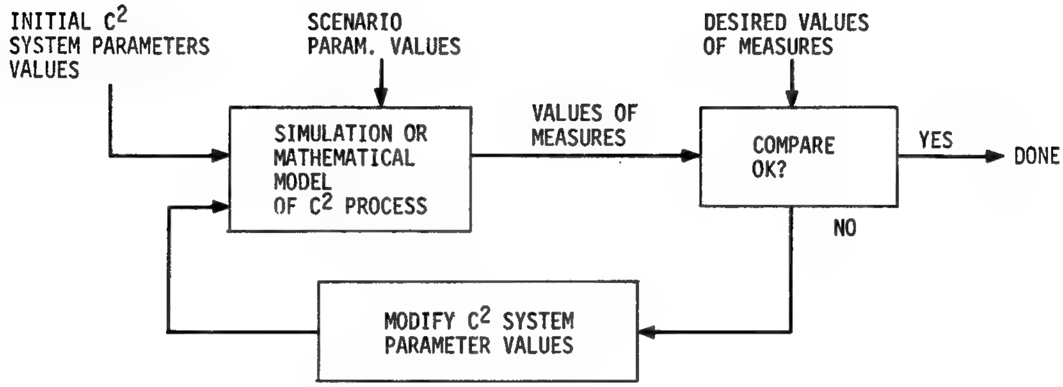

FIGURE 6-2
ANALYSIS OF MODELED C^2 SYSTEM

performance characteristics, enemy system survivability/endurance characteristics, enemy strategy and tactics, and order of engagement events versus time). The analysis process consists of starting the model with initial C^2 system parameter values and scenario data and computing the values for the measures (possibly versus time). If the computed measure values are acceptable, then the process stops. If not, the C^2 system parameter values are improved to increase system performance or effectiveness and the process continues until the computed measure values are as good as the desired measure values.

The model can be used to perform a tradeoff analysis to determine the most cost-effective system as described in Figure 6-2. The model can also be used to perform a sensitivity analysis to determine the effects of perturbations of system and scenario parameter values on the measures of performance/ effectiveness. These sensitivities will be relative to the nominal values assumed for the various parameters. (This is similar to partial derivatives at a particular point for a multivariate function.) The model can also be used to examine system performance versus system survivability and endurance tradeoffs for fixed-system cost.

6.4.2 Analysis Using Actual System

During the acquisition or operation phases, a system analysis can be performed on the actual system being evaluated. The system can be in the R&D phase, test and evaluation phase, or operation phase. During the R&D phase, the decision on the system being developed is, "Is it feasible to continue R&D on this system?" In the test and evaluation phase, the question is, "Is the system ready for operational deployment?" In the operation phase, the question is, "Is this system satisfying current or planned operational requirements?"

6.4.2.1 Areas of Application. Testing can be conducted in the laboratory, field, or after implementation in the operational environment. The analysis process requires the availability of input data for the system being tested. This data can range from simple electrical signals generated in the laboratory or within the system itself, such as a stimulator in a radar, to very complex scenario data generated for a large force/C^2 structure by a large computer simulation.

For the system analysis using the actual system, the process is essentially open loop in that no iterative procedures for modifying the system are used (see Figure 6-3). The analysis process previously described in this chapter should be employed regardless of whether a model of the C^2 system or the actual system is being used in the study.

6.5 Selection of Measures: Two Illustrations

As previously mentioned in this paper, there are both performance and effectiveness measures. Effectiveness measures describe how well the C^2 system meets its requirements. Force effectiveness measures describe the contribution of the C^2 system to the overall force mission performance. Most military analysis is force oriented in the sense that the ultimate issue usually concerns the marginal contribution to force effectiveness of various systems, tactics, or force structure changes. Accordingly, the analyst's goal is to relate improvement, for example, in system performance, to the ability of a force to accomplish a specific mission. It should, therefore, not be surprising that the focus of attention in selecting measures for a particular analysis is initially directed toward the force and its mission.

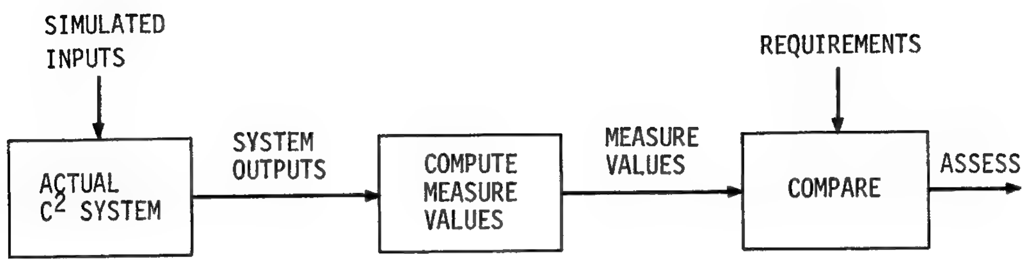

FIGURE 6-3
ANALYSIS OF ACTUAL C^2 SYSTEM

6.5.1 Evaluating a Tactical Warfare C^2 System

As an example, let us consider an air-defense C^2 problem. Table 6-5 provides a hierarchical structure of measures developed in the fashion described above. In this particular situation, assume we are interested in evaluating the contribution of the C^2 system to force-mission accomplishment.

6.5.1.1 Level 1. The air-defense force consists of both air and ground elements. Assuming that the primary mission of air defense is to "protect friendly forces," two appropriate effectiveness measures would be "friendly losses" or "friendly losses due to enemy air attack." A measure sometimes used to assess the contribution of friendly air defense is "enemy aircraft losses." Such a measure, however, fails to take into account that the air-defense force can provide some protection without necessarily destroying enemy aircraft. Specifically, this additional protection derives from the "suppression" capability of the air-defense force which frequently reduces "friendly losses" but does not result in increased "enemy aircraft losses." While the "enemy aircraft losses" is potentially a useful air-defense system measure, if used in isolation, it can mask valuable information. Similar examples occur in other areas of military analysis.

6.5.1.2 Level 2. Proceeding down the hierarchy, a major component of the air-defense force is the C^2 system. The C^2 system is responsible for allocating friendly air-defense resources in response to the threat as it develops, while at the same time alerting the remainder of the friendly force of impending air attacks. Measures appropriate for the former task are: "fraction of engagement opportunities exploited," and "fraction of air-defense resources needed to respond to a given level of threat." An example of a measure that addresses the alerting mission of the air-defense C^2 system is the "early warning time" afforded the friendly force.

TABLE 6-5

MEASURE HIERARCHY

HIERARCHY LEVEL	SYSTEM LEVEL	MISSION/TASK	MEASURES
1	Air Defense Force	Protect Friendly Forces	Friendly Losses
2	C^2 System	a. Alert Forces b. Resource Allocation	A. Early Warning Time b. Fraction of Engagement Opportunities Exploited
3	Acquisition Radar	Detection	Time to Detect

6.5.1.3 Level 3. At the bottom of the hierarchy is the acquisition radar, an element of the air-defense C^2 system. As we have previously seen, the primary task of the radar is to detect targets in the shortest possible time. An appropriate measure is the "time to detect, given line of sight to the target."

6.5.2 Evaluating a Strategic C^2 System

The selection of effectiveness measures for strategic systems is usually more straightforward than for tactical systems, primarily because the strategic mission is traditionally open ended with little feedback. Relating this to our conceptual model, we are often not interested in feedback into the environment with further sensing changing the decision. This view may be simplistic but, for Positive Control Launch for survival of strategic systems, it is usually true. For this example, assume an interest in evaluating the contribution of a new Tactical Warning/Attack Assessment (TW/AA) communications system to force-mission accomplishment. The starting hypothesis is that warning data from sensor sites is not reaching the decisionmakers in sufficient time to ensure mission accomplishment. Since the major time delay is in the communications subsystem in a jamming and nuclear environment, the focus is on that element of the force. Table 6-6 describes a hierarchy of measures for such a situation.

6.5.2.1 Level 1. To define measures, the mission of the force must be clearly defined. A broad statement of the strategic mission such as "deter aggression" lacks sufficient detail to use as a measure of effectiveness or performance. Breaking the mission into "ensuring enough forces survive, and executing war orders to inflict unacceptable damage on an aggressor" refines the mission but does not provide an easily measurable yardstick of system performance, i.e., what is unacceptable. More practical operational measures

TABLE 6-6

MEASURES FOR STRATEGIC C^2 SYSTEMS

HIERARCHY LEVEL	SYSTEM LEVEL	MISSION/TASK	MEASURES
1	Strategic Force	a. Deterrence b. Provide for Surv. of Force c. Execute the War Order	a. Damage to an Aggressor Compared to Gains b. Weapons Surviving and Connected c. Weapons on Target
2	C^2 System (TW/AA and Command Centers)	a. Track All Threats b. Alert Decision	a. Sensor Coverage b. Warning Time c. Data Correctness d. Decision Time
3	Comm. Element	a. Connect Sensor to TW/AA System	a. Time to Transmit b. Reliability Availability, etc. c. Manpower a. Additional Weapons Surviving Based on Comm. System

would be "% or number of weapons surviving" or "% or number of weapons on target." To reflect the importance of communications we can further refine the force measure to weapons surviving and connected. These measures can be combined with other weapons system and personnel measures to define an overall force measure of damage to an aggressor compared to his gains. Using the definitions from Chapter 2, these force-level measures are MOFEs.

6.5.2.2 Level 2. A major piece (subsystem) of this force is the C^2 system. Our interest is in the TW/AA subsystem whose mission is to identify and track threats, alert the forces, and provide recommendations to decisionmakers. Appropriate measures would be response time, percentage of threats the system can handle, and saturation. Examples of goals which can be measured include receipt of data, processing and forwarding to decisionmakers in five minutes; tracking Intercontinental Ballistic Missiles, Sea-Launched Ballistic Missiles (SLBMs), bombers and cruise missiles over one square meter radar cross section and above a 300-foot altitude; or handling 1,000 targets simultaneously. A less obvious measure stemming from the force mission of deterrence would be false-alarm detection rate. Launching a counterattack against a non-existent aggressor starts war, it does not deter it.

6.5.2.3 Level 3. The focal point of this analysis is the contributions of a new communications system to TW/AA and force effectiveness. This is the lowest level of the analysis, which will be called the subsystem level. Requiring the component to send a message from point A to point B is not sufficient. The focus is now directed toward reliability, maintainability, timeliness, usability, and other aspects of system specifications. At the lowest level, the most obvious classes of measures address the following questions:

a. How well does the equipment performance (physical parameters) meet system performance requirements?

b. Can the system be operated by the two men per transmitter available to the user?

c. Will this system overload the processing center?

d. Does the system provide 99% reliability, 98% availability, and 90% accuracy of transmitting data from a particular sensor to the processor?

e. Will the system create less than 1 in 100 million wrong messages in jamming and nuclear environments?

Measures of 75 baud minimum data rate, six messages simultaneously (traffic volume), and availability of 98% at the subsystem level can be directly related to MOFEs. Weapons surviving, especially aircraft resources escaping their bases under an SLBM and cruise missile attack, can be directly related to how fast the communications system sends warning data from the sensors to the processing centers and then to the decisionmakers. Human decision time measures at the force level may, at this point, render this analysis useless if decision time rather than the communications system starts to drive the scenario.

CHAPTER 7

MATHEMATICS

by
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7.0 INTRODUCTION

Beyond developing a conceptual framework for viewing a C^2 process, it is important to consider a mathematical/heuristic method that can be used for design, evaluation, or tradeoff studies. For this purpose, a C^2 system can be represented abstractly as a transformation that maps a collection of inputs (primarily in the form of sensed data and status reports) into outputs (generally in the form of plans and schedules for effecting resource allocations). Another set of inputs, referred to here as internals, includes mission definition, objectives and characteristics, historical data bases, standards, and procedures that will be viewed as resident in the system and fixed during the period of interest.

As stated above, this methodology is intended for use in design, evaluation, and tradeoff analyses:

a. The design problem begins by defining desired outputs and measures which will be used to assess system performance against design objectives. The inputs and internals needed to provide the data and information required to produce those outputs and the mechanism for transforming the inputs into the desired outputs are then derived. The initial design approach is often top-down, with the designer using organizational, functional, spatial, or temporal decomposition to identify the required inputs, internals, and transformations.

b. Operators use systems to perform a mission. In operations analysis, performance of the system is often evaluated using a bottom-up approach wherein low-level performance measures are combined to determine system performance. Designers also use this approach in detail design.

c. In the acquisition stage of the system life cycle, both top-down and bottom-up approaches to analysis are needed. The top-down approach assists the program manager to focus on those system elements which most affect overall effectiveness when making cost-effectiveness calculations. The bottom-up approach allows comparative evaluation of alternative well-defined competing approaches.

7.1 MOEs - Attributes and Requirements

In the previous sections, a conceptual framework for the development and use of models for generating quantities to be used in measuring effectiveness was presented. Specifically, it was shown that a mission has implicit in its definition the attainment of one or more goals. The achievement of these goals, in turn, gives rise to a set of critical attributes that the system must possess. These attributes can be very general, as concepts, but their quantitative interpretation is invariably highly mission dependent. For example, the attributes of timeliness, responsiveness, or robustness convey intuitive concepts rather well. However, as Lawson (1981) has written, "in a typical discussion of C^2, it is taken as axiomatic that the information presented to the commander must be timely as well as accurate, complete, etc. . . . . Little or nothing is said about how timely is timely enough . . . ." Thus we need to go a step further and define a set of variables that expresses concretely these concepts for a given mission context. For example, the ratio of the time to cycle through the C^2 process for a particular task to the inter-arrival time of tasks may be one of the variables that is key to the concept of timeliness for a given mission. Moreover, it may occur that more than one variable is needed to interpret a given attribute.

Often, it is also necessary to consider tradeoffs between attributes such as timeliness and completeness or timeliness and accuracy. Again this will depend on definitions of variables that interpret more precisely the attributes for a given mission to allow comparisons among values resulting from different C^2 system realizations. These variables will be called "Variables for Measuring Effectiveness" (VFMEs).

The basic approach to developing attributes and converting them into requirements for design or evaluation appears to consist of three steps:

a. Extracting from an expert (e.g., the responsible commander) the attributes of C^2 that are essential to achieve desired mission performance.

b. Associating with each of these C^2 attributes specific variables that measure the performance of the attribute.

c. Using simulation to establish acceptable values for the variables to achieve required mission performance. Typically this step will result in intervals for each variable, such as probability of detection greater than some value.

If not carefully treated, this last step can lead to errors in system design. These errors arise because the intervals chosen to establish requirements do not, in general, account for the dependence among the variables. Thus, as portrayed in Figure 7-1, v_1^1 and v_1^2 both acceptable values for the variable v_1 but for different, though overlapping, values of v_2. Thus, if one merely projects the acceptable region onto the v_1 and v_2 axes to get acceptable intervals to define requirements of the variables v_1 and v_2, the system designed may actually give rise to a pair (v_1^*, v_2^*) that lies outside the acceptable region. It is

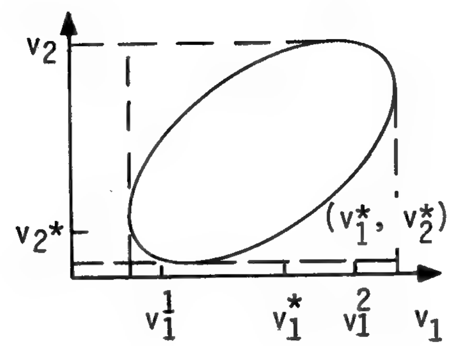

FIGURE 7-1
VARIABLES OF MISSION PERFORMANCE

believed that this is the cause of failures in many system designs which integrate a collection of subsystems, each of which seems to be properly designed and meets the design specifications. This issue will be addressed again later in this chapter.

7.2 A Probabilistic Formulation

This section presents a mathematical theory to determine (1) when sufficient attributes and variables for measuring them have been defined; (2) how to use these variables to set requirements, (3) how to define mathematically a system measure of effectiveness, and (4) how to use the definition to evaluate system designs.

7.2.1 Sufficiency for the Set of Variables for Measuring Effectiveness

Assume that the combat situation of interest has been modeled in detail in such a way that the various C^2 processes and systems can be included in a realistic fashion. Call this model M. Conceptually, this model is viewed as a monte-carlo simulation which gives a set of combat outcomes for each replication.

Let S be the set of all C^2 system realizations of interest, including all variations of the same system obtained by taking variations of the operating parameters.

The set $\{M,S\}$, consisting of the simulation M and a well-defined set, S, of C^2 systems, which will serve as the universe of system alternatives, provides a well-defined context for analysis purposes.

Let $\underline{v} = (v_1, \ldots, v_m)$ be a vector of the given VFMEs of command and control that express the important mission-dependent notions of completeness, accuracy, timeliness, and so on. The vector $\underline{v}$ is considered to be random, since each replication will provide a simulated real-world outcome with different time delays, targets detected, etc. Let $\underline{c} = (c_1, \ldots, c_n)$ be the random vector of combat outcomes of interest to the operational commander (e.g., enemy resources destroyed, own resources lost).

For each replication of the simulation M with C^2 system $s \in S$, one obtains realizations, i.e., values, for $\underline{v}$ and $\underline{c}$. By taking enough replications one can estimate the joint distribution function for $\underline{v}$ and $\underline{c}$ and, more important, the conditional probability measure, μ for $\underline{c}$ given $\underline{v}$ and s. This means that for a set, Θ, of combat outcomes one can derive the probability,

$$\mu(\Theta|\underline{v},s),$$

that an outcome, $\underline{c} \in \Theta$, will occur, given $\underline{v}$ and s.

Definition: the VFMEs, which are the elements of $\underline{v}$, are said to be sufficient for measuring effectiveness if $\mu(\cdot|\underline{v}, s)$ does not depend upon s for $s \in S$, i.e., if $\mu(\cdot|\underline{v}, s) = \mu(\cdot|\underline{v})$.

Intuitively, this means that if $\underline{v}$ is sufficient for measuring effectiveness, the essence of the C^2 system within the universe has been captured by $\underline{v}$. Clearly one seeks the sufficient vector $\underline{v}$ with lowest dimension.

7.2.2 Setting Requirements

Next, it is necessary to establish requirements for values of the VFMEs so that individual components of the system may be designed with the assurance that, when the total system is constructed, it will achieve the desired objectives.

The requirements are set as follows. The "military expert" establishes a set of desired combat objectives to be achieved, with some probability, in terms of the vector $\underline{c}$. For example, let c_1 be the percentage of planned targets destroyed, and c_2 be the percentage of own aircraft lost. Then the objective set might be $\Theta = (c_1, c_2)$, where

$$c_1 \geq 90\%, \text{ and}$$

$$c_2 \leq 10\%,$$

with probability of being in Θ, 0.95 or higher.

The conditional probability measure, μ, which is independent of any particular C^2 system $s \in S$ because $\underline{v}$ is sufficient, is used to define requirements. The requirements set, R, is defined by

$$R = \{\underline{v} : \mu(\theta|\underline{v}) \geq .95\}$$

All tradeoffs in attributes are implicit in R.

7.2.3 Measuring C^2 System Effectiveness

Returning to a specific C^2 system $s \in S$, it is desired to define its measure of effectiveness so that systems can be rank ordered. For a set of objectives and a particular vector of VFMEs $\underline{v}$, it has been shown how to define the probability of achieving the objectives, $\mu(\theta|\underline{v})$, and how to define the requirement set R.

Effectiveness, E(s), of $s \in S$ is now defined to be

$$E(s) = \int_R \mu(\theta \,|\underline{v}) dF_s(\underline{v})$$

where F_s is the probability distribution of the VFMEs for the C^2 system s. Note that a C^2 system that causes $\underline{v}$ to fall outside R with high probability will receive a low value for E and a C^2 system that meets the requirements with high probability will receive a high value, which is consistent with what a measure of effectiveness should provide.

7.2.4 Evaluating System Designs

This measure of effectiveness, E, allows a comparison between potential systems based on how they influence combat outcomes. Moreover, if S consists of a finite number of candidate systems, an "optimal" choice can be made.

7.3 A Constructive Approach

The last section presented a mathematical formulation that allows the definition of a requirements set and a measure of effectiveness for use in comparing system alternatives. This

section presents a constructive approach for making such comparisons.

Let the VFMEs of the C^2 system be denoted by the vector $\underline{v}$ (the vector $\underline{v}$ is assumed to be sufficient in the sense of Section 7.3.1). For simplicity of presentation, it will be assumed that the variables take values that are real numbers ($\underline{v} \in R_m$). However, this need not be the case; some of them may take linguistic values such as "fast" or "slow." Let the environment be described by a vector $\underline{r}$.

7.3.1 Setting Requirements

Requirements can be obtained by setting values (or ranges of values) for the variables v_i. In order to do that, however, it is necessary to go outside the boundary of the C^2 process. A set of models is required that allows the mapping of the variables v_i to the variables for measuring mission outcomes, c_i. The values of these variables are determined from the combat models as the variables $\underline{v}$ and the environment descriptors $\underline{r}$ are varied, that is:

$$\underline{v}, \underline{r} \rightarrow \underline{c}$$

This mapping can be represented pictorially as shown in Figure 7-2.

If the vector $\underline{v}$ can take values, $\underline{v} \in V \subseteq R_m$, then the variables c_i can take values over a corresponding range in their space, i.e., given $\underline{r}$ for

$$\underline{v} \in V \subset R_m, \qquad \underline{c} \in C \subset R_n$$

Graphically, if the vector, $\underline{v}$, is two dimensional and the vector, $\underline{c}$, is three dimensional, then the region V in the left side (a) of Figure 7-3 maps onto the region C in the right side (b) of Figure 7-3.

For example, consider a case with two such measures: c_1, that reflects the degree of success in destroying targets, and c_2, that reflects survivability through a measure of own aircraft lost.

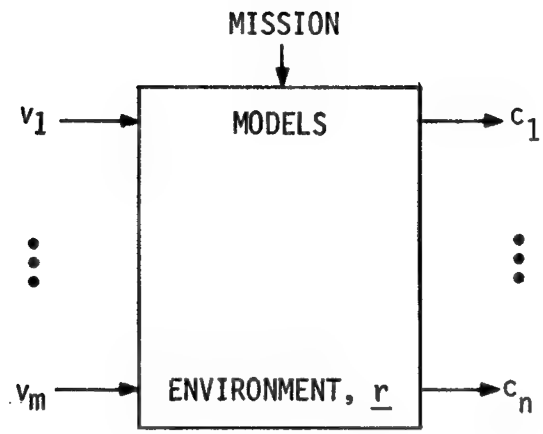

FIGURE 7-2
MAPPING OF VARIABLES

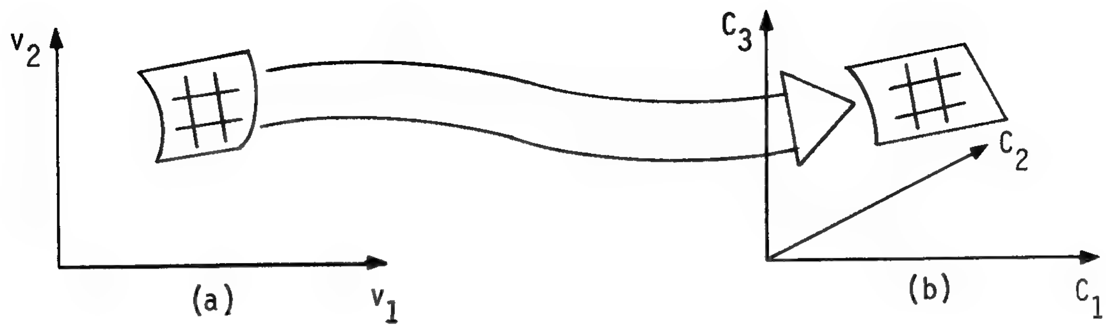

FIGURE 7-3
MAPPING REGIONS

Then, for a given subset in the space defined by the vector, $\underline{v}$, the evaluation of c_1 and c_2 can be obtained through the use of battle simulation models. These models should be as complete as is required for the problem at hand. Therefore, for example, they may have embedded in them models of the Red force.

The locus in the space of the mission measures shows the tradeoff between success and survivability. Assume the command has established an acceptable level of losses ($c_2 \leq c_2^*$) and a minimum degree of success ($c_1 \geq c_1^*$).

The cross-hatched regions in Figure 7-4 (a,c) indicate the unacceptable portions of the tradeoff region. In this example, there is an acceptable range where satisfactory performance in meeting mission objectives can be achieved at an acceptable level of losses. This range can be realized, if the vector $\underline{v}$ takes values in the portion of the region V that is not cross-hatched.

While many different models may be used to obtain values for the quantities c_i, it is important that consistent sets of values be obtained. This implies that **the various models should be exercised for the same values of $\underline{v}$ and $\underline{r}$ to obtain a mutually consistent set of values for the variables c_i.** Comparison between systems can be made by varying the variables $\underline{v}$, for a fixed mission and fixed set of environmental conditions.

If the environmental parameters $\underline{r}$ are changed and the procedure repeated, then a new region, C', will be obtained. Indeed, a whole family of regions can be obtained as the environmental parameters vary. Each region characterizes the performance capabilities of the process for a given mission and for a given set of environmental conditions (or context).

Thus, one can derive a family of regions, V, parameterized over the environment vector $\underline{r}$. Each such region yields a tradeoff locus C. In general, some of the loci will have no acceptable

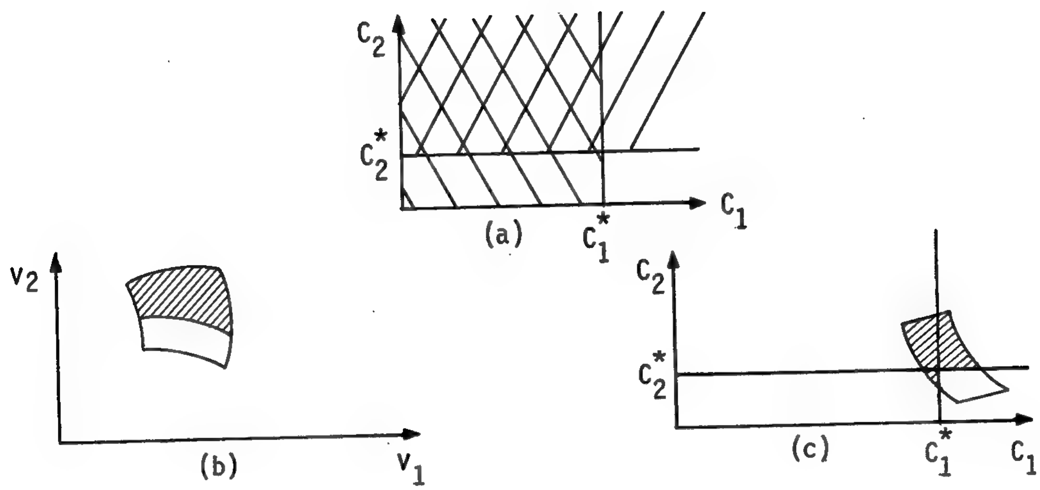

FIGURE 7-4
TRADEOFF REGIONS

range (Figure 7-5(a)), while for other values of $\underline{r}$ the whole locus may be acceptable, as shown in Figure 7-5(b).

Extreme cases for the illustrative example would be:

a. Weather conditions and enemy defenses are such that the expected value of targets destroyed is very low, while losses from enemy defenses and/or weather conditions are exceedingly high (Figure 7-5(a)).

b. Weather conditions are excellent and the opposing forces have no anti-air capability (Figure 7-5(b)).

Considerations of the admissible portions of the tradeoff locus, C, parameterized over the vector $\underline{r}$, lead to the admissible ranges of the vector $\underline{v} \in V$. Since, in general, it may not be possible to invert the mapping from $\underline{v}$ to $\underline{c}$, the correspondence between them is obtained when the mapping from $\underline{v}$ to $\underline{c}$ is obtained through means such as simulations, exercises, and war games.

The set of admissible values, Va, of the variables for measuring effectiveness, of the C^2 process leads directly to requirements of the general form:

$$v_{i0} \leq \underline{v}_i \leq v_{i1}$$

With the setting of requirements for the C^2 process, it is now possible to address the question of effectiveness.

7.3.2 Measures of Effectiveness

Implicit in the notion of assessment or evaluation or measuring the effectiveness of C^2 system is the concept of a standard. If the requirements represent a standard, then comparison of the measures of performance to the corresponding requirements for these measures leads to measures of effectiveness. Sometimes the comparison is explicit, when one measures by how much a measure of performance exceeds a given level of performance. Sometimes it is implicit, when the measure itself is a deviation such as the probability of error.

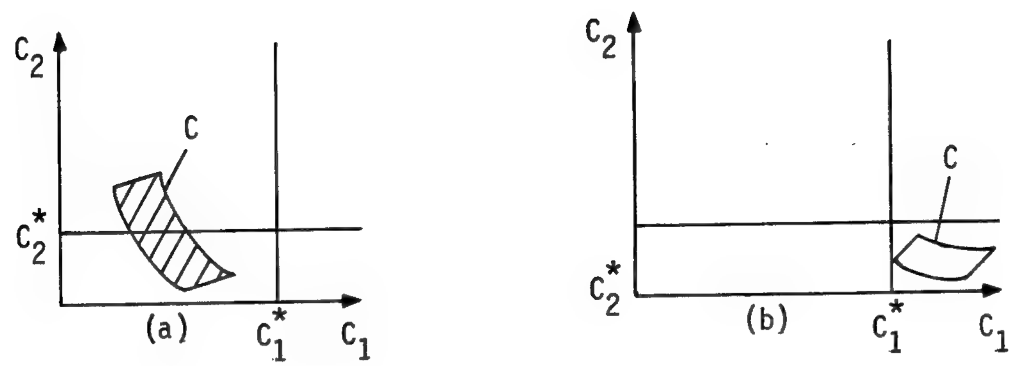

FIGURE 7-5
TRADEOFF LOCI

Up to now, a top-down approach has been used: the mission goal was expressed in terms of several objectives, the C^2 process was characterized by a number of attributes, these attributes were expressed in terms of measurable variables and, finally, requirements were established, i.e., admissible ranges for the values of these variables. The system developers then design systems that support the functions of the C^2 process.

It has already been shown in the previous subsection how the requirements can be defined from a locus, i.e., a region, V_a, in the space defined by the vector $\underline{v}$. In an analogous manner, there is a locus, V_s, in that same space that is defined by the values of $\underline{v}$ that can be realized by alternative system designs.

To obtain V_s let the parameters of the C^2 system, as defined in Chapter 2, be denoted by the vector, $\underline{p}$. Again, for simplicity of presentation, it is assumed that the parameters take values that are real numbers, i.e., $\underline{p} \in R_k$. Using simulations that relate system performance as measured by the variables, $\underline{v}$, to the system parameters, $\underline{p}$, one can determine the values of $\underline{v}$ as the parameters, $\underline{p}$, and the environmental descriptors, $\underline{r}$, are varied as indicated below and in Figure 7-6.

$$\underline{p}, \underline{r} \rightarrow \underline{v}.$$

In this way one can determine the set, V_s, which includes the values for the VFMEs that are achieved for a class of designs. Summarizing, let the set of admissible values (for acceptable mission outcomes) of $\underline{v}$ be denoted by V_a and let the set of values of $\underline{v}$ realized by a system design be denoted by V_s. In general, $V_s \neq V_a$, and acceptable system designs will only correspond to those which have parameters, $\underline{p}$, such that

$$\underline{p} \rightarrow \underline{v} \in V_s \cap V_a.$$

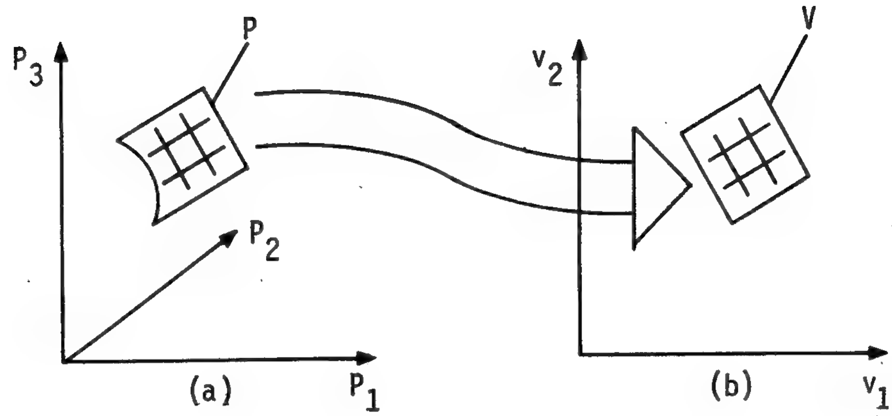

FIGURE 7-6
RELATIONSHIP OF SYSTEM PARAMETERS AND ENVIRONMENTAL DESCRIPTORS

The necessary ingredients are now in hand to consider the problem of evaluating overall system effectiveness in the presence of multiple criteria. One way that a comparison can be made is by analyzing separately each dimension, i.e., each of the VFMEs. A metric can be established for each dimension and a value calculated. For example, the C^2 system may exceed substantially the timeliness requirements, may barely satisfy the robustness and flexibility requirements, may be responsive, but can only support one mission at a time. How does one establish an absolute measure of effectiveness, i.e., this system is or is not very effective, and how does one compare two alternative systems, i.e., this system is more effective than that?

The existence of a vector of VFMEs leads to both conceptual and technical problems in evaluating systems. There are problems associated with attempts to map the vector into a scalar by considering weighted averages of the components of the vector. There are issues associated with trading off between variables without due consideration to their scaling. In addition to these issues, which arise in many of the commonly used approaches, there are subtle issues related to the fact that, while each component of the vector $\underline{v}$ may take values over a range, the n-tuple itself that corresponds to the vector is constrained to lie on a surface or locus. This means that one cannot consider each variable as being able to take values anywhere in its range, independently of the values taken by the other variables (see Figure 7-1).

One possible approach that avoids these problems is based on an intuitive notion. If a system meets or exceeds all the performance requirements derived from the considerations described in Section 7.3.1, then this would be an effective system. If a system does not meet any of the requirements, then it is ineffective. Since a system's performance is not characterized by a single point

in the space defined by the VFMEs, the usual case is that one portion of the locus V_s, the performance locus, will satisfy all requirements, while the other portion will satisfy only some of the requirements. A possible means for ordering alternative systems and for computing an absolute value of effectiveness is to measure the extent to which the locus V_s lies within the admissible region V_a.

For example, as one varies the environmental parameters $\underline{r}$, one obtains different values of $\underline{v}$. If most of these values of $\underline{v}$ meet the requirements, then the C^2 system would be effective for this mission. Furthermore, one may parameterize over missions and again compare the resulting set of $\underline{v}$ values to the requirements.

Mathematically, we define a function, m with domain V. This function may be, for example, the area of the surface defined by V_s, or, if V_s consists of a finite set of points, it may be the number of points in V_s.

Now consider the portion of V_s, denoted by V_e, that meets the requirements, i.e., the portion of the surface that is within the region defined by the requirements. This can be expressed as the intersection of the two sets (or loci)

$$V_e = V_s \cap V_a$$

If all points satisfy the requirements, then

$$V_e = V_s$$

If no points satisfy the requirements, then

$$V_e = \phi$$

A scaled measure of effectiveness is then the fraction of the system performance locus that satisfies the requirements:

$$MOE = \frac{m(V_e)}{m(V_s)} = \frac{m(V_s \cap V_a)}{m(V_s)}$$

This very simple measure does not distinguish between values of $\underline{v}$ that barely exceed the requirements and values of $\underline{v}$ that significantly exceed the requirements. These considerations could be modeled through a weighting function $w(\underline{v})$, introduced into the function m, that assigns different weights to different portions of the requirements locus. This approach also would allow, for example, accommodation of styles of command, expressed in terms of risk-taking behavior, such as intuitive versus deliberate styles, if they are known or elicited from the commander.

7.3.3 Sensitivity Analysis

The mathematical framework described herein allows the evaluation of the sensitivity of the above-defined MOE to the variables for measuring effectiveness. This can be expressed formally as the ability to take the derivative of the MOE with respect to the vector $\underline{v}$:

$$\frac{d\,MOE}{d\underline{v}}$$

Of course, this is only a formal expression since the MOE may not be differentiable. Differences would then be used:

$$\frac{\Delta MOE}{\Delta \underline{v}}$$

A more interesting result, that allows one to confirm experience from the user and the system developer communities, is the calculation of the sensitivity of the MOEs to C^2 system parameters:

$$\frac{d\,MOE}{d\underline{p}} = \frac{\partial MOE}{\partial \underline{v}} \cdot \frac{\partial v}{\partial \underline{p}}$$

The last term on the right expresses changes in the variables for measuring effectiveness to changes in the system parameters, i.e., it reflects the sensitivity of these variables to the system

parameters. These are quantities that the system developers usually estimate or calculate as part of the design process. The preceding term is the quantity that analysts would calculate.

7.4 Conclusion

In this section, a mathematical framework has been outlined that attempts to interpret some of the technical issues in measuring effectiveness. The mathematical formalisms (probability, vectors, sets, spaces, surfaces) were chosen only for illustrative purposes and in order to make the discussion more concrete. However, there is no requirement that the variables must take real, numerical values, that they be continuous, or that the various mappings be constrained to be functions of real variables. Indeed, other formalisms have been proposed and can be used, e.g., fuzzy sets, as appropriate.

CHAPTER 8

SUMMARY

by
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The hypothesis contained in the previous chapters is that there is a generic structure which has great utility in the evaluation of C^2 systems. This chapter briefly reviews this structure and the status of its proposed modular building blocks. We will then propose that a test of this hypothesis be conducted in another Workshop in January 1986.

The architecture of this report, as discussed in Chapter 3 and again shown as Figure 8-1, is based on a suggested set of definitions for C^2 system evaluation in Chapter 2. These definitions provide a means of specifying both the system under evaluation and the measures for evaluation. They are a function of where the boundary is drawn around the system at hand. This approach is common to all disciplines which use systems concepts. The bulk of this report describes the use of these concepts to better evaluate C^2 systems.

The evaluation structure is application driven. We believe that such a structure is most needed in the difficult task of preparing comparable measures about dissimilar systems which are competing alternatives for budget decisions, i.e., C^2 versus weapons systems.

A specific application and distinction of systems boundaries provides a basis for specifying these analytical modules for the important development and generation of MOEs. Data sources, parameter types, and mathematical formulations then follow. The ultimate goal will be to identify the mix and match of applications, boundary conditions, models, and measures as well as techniques for data collection. Such a "menu" approach facilitates the structuring of analyses and provides clearer explication and agreement on the analytic

What is the Structure?

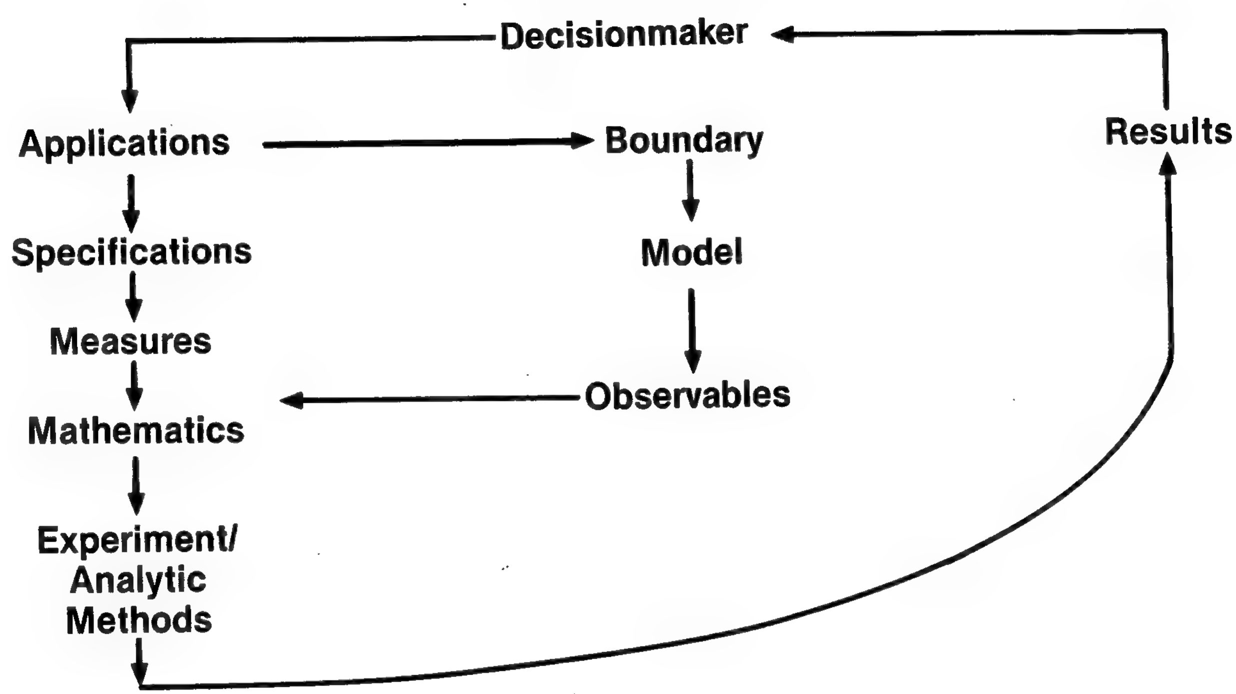


FIGURE 8-1
STRUCTURE — ARCHITECTURE

approach being used. This, in turn, properly focuses attention upon assumptions being made, analytical factors, and system parameters, and the results obtained. (See Figure 8-6.)

The evaluation structure remains incomplete. Additionally, the approach generated needs to be applied to some real-world problems to assess its utility and generality. The results of the applications should be assessed as test results. The approach can be judged as achieving validity if realistic solutions are provided. If not, we need to determine why and where it needs to be modified. In this way, the state-of-the-art of evaluating C^2 systems can be advanced. This test concept will be discussed after each chapter is summarized below.

Chapter 2 started with the necessary definitions. First, C^2 is:

Command and Control: As defined in JCS Pub 1:

> "The exercise of authority and direction of a properly designated commander over assigned forces in the accomplishment of his mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishments of his mission."

A C^2 System has two components (a. and b. below), when at rest, and a dynamic state (c. below):

a. Physical Entities: Equipment (computer and peripherals, modems, antennas, local-area networks), software, facilities, and people.

b. Structure: The arrangement and interrelationships of physical entities, standard operating procedures, protocols, concepts of operation, and information patterns. (Structure frequently reflects doctrine and may be scenario dependent.) Such arrangements are often physical and temporal.

c. C^2 Process: Refers to the system in its dynamic state. It says: "What is the system doing?" It reflects functions carried out by the C^2 system--sensing, assessing, generating, and selecting alternatives, i.e., the behavior of the system.

C^2 System Boundaries: The "boundary of a C^2 system" is defined as a function of the analysis at hand, and is the delineation between the system being studied and its environment.

Definitions of measures applied to command and control are presented below:

a. Measured/Specified Inside the Boundary of the C^2 System:

   1. Dimensional Parameters - The properties or characteristics inherent in the physical entities whose values determine system behavior and the structure under question, even when at rest (size, weight, aperture size, capacity, number of pixels, luminosity).

   2. MOP - These are also closely related to inherent parameters (physical and structural) but measure attributes of system behavior (gain throughput, error rate, signal-to-noise ratio).

b. Measures/Specified Outside the Boundary of the C^2 System:

   1. MOE - Measure of how the C^2 system performs its functions within an operational environment (probability of detection, reaction time, number of targets nominated, susceptibility of deception).

c. Measures/Specified Outside the Boundary of the Force:

   1. MOFE - Measure of how a C^2 system and the force (sensors, weapons, C^2 system) of which it is a part performs missions.

Chapter 3 emphasizes the use of measures in the conceptual as well as the implementation categories of C^2 system development. We have stressed the conceptual area since we believe it has not received sufficient attention in the past. The application categories identified in Chapter 3 are shown below:

Conceptual

Doctrine Development

Requirements Generation/Validation

C^2 Contribution to Force Effectiveness

New Technology Assessment

R&D Goals

Implementation

POM/Budget Process

Acquisition Process

Technical Evaluation

Operational Evaluation

In Chapter 4, a conceptual model of the C^2 process, as shown in Figure 8-2, has been created from several progenitors, primarily the Lawson model. It has been expanded in terms of both two-sided and hierarchical dimensions. The subprocesses have been described but not quantified. We believe that this generic process model is now reasonably robust and can serve as a guide for the development of detailed process models (where necessary for a particular analysis) or tests that will generate measures far more relevant than the isolated "system at rest" measures often seen in the past. The steps in this development are shown in Figure 8-3. The measures derived should have the characteristics shown in Table 8-1. It is important to note that the process model does not model system components themselves. This may be necessary in some analyses.

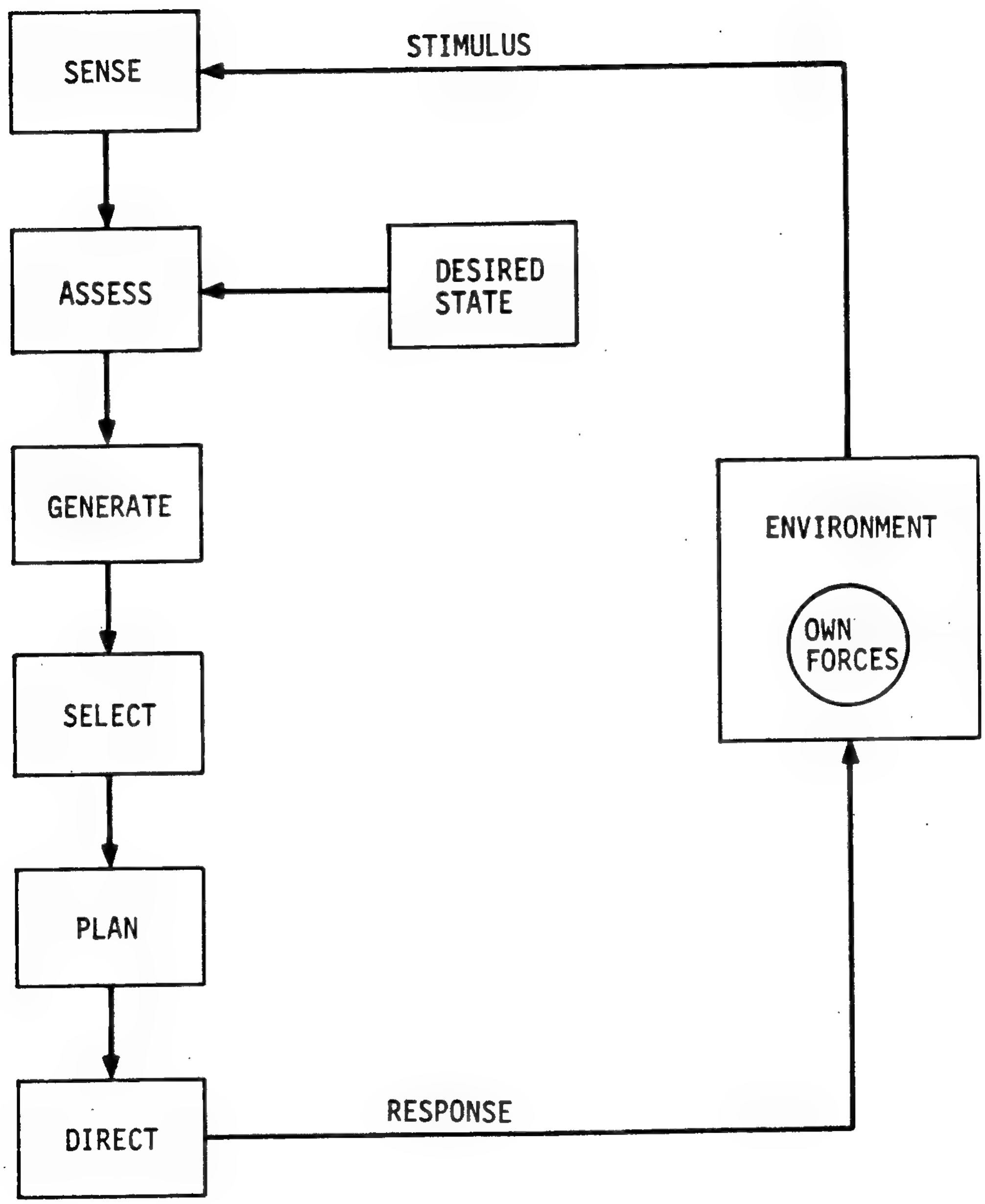


FIGURE 8-2
CONCEPTUAL C2 PROCESS MODEL

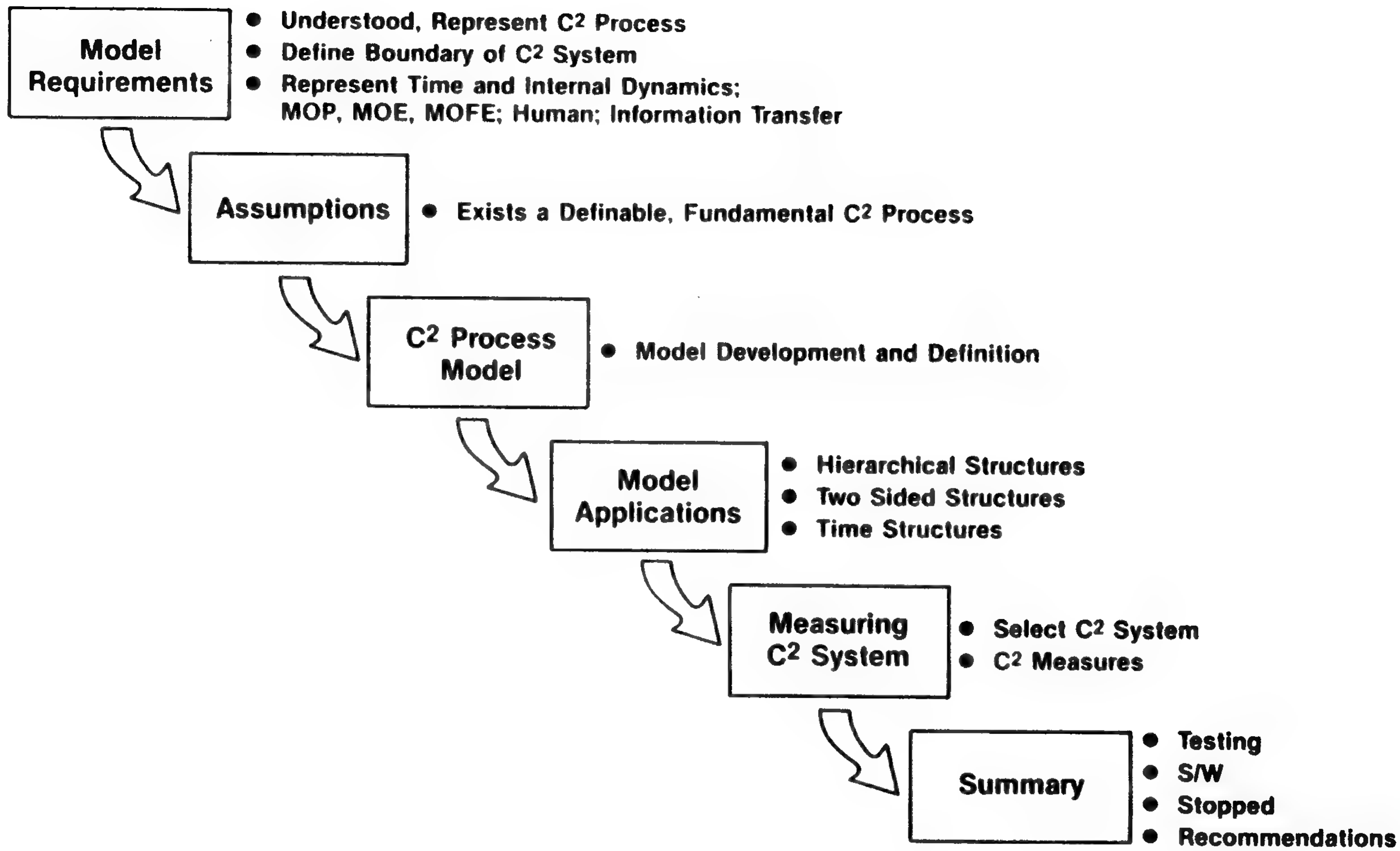


FIGURE 8-3
APPROACH

TABLE 8-1

DESIRED CHARACTERISTICS FOR MEASURES

CHARACTERISTICS	DEFINITION
Mission oriented	Relates to force/system mission.
Discriminatory	Identifies real difference between alternatives.
Measurable	Can be computed or estimated.
Quantitative	Can be assigned numbers or ranked.
Realistic	Relates realistically to the C^2 system and associated uncertainties.
Objective	Can be defined or derived, independent of subjective opinion. (It is recognized that some measures cannot be objectively defined.)
Appropriate	Relates to acceptable standards and analysis objectives.
Sensitive	Reflects changes in system variables.
Inclusive	Reflects those standards required by the analysis objectives.
Independent	Is mutually exclusive with respect to other measures.
Simple	Is easily understood by the user.

Any C^2 system will be developed through a life cycle which is composed of three phases: (1) design, including concept definition and development; (2) acquisition and development; and (3) operational. The objectives of the three phases, respectively, are to:

a. Develop a concept design, desirable characteristics, and broad requirements to meet mission objectives and/or specify system requirements, and perform early R&D.

b. Develop detailed designs and acquire the system.

c. Deploy and evaluate the operational system (and sometimes improve the system or improve how the system is used). It is important to realize that in some analyses the hardware and software aspects of a system under analysis can be relatively unimportant compared to the structure chosen and the procedures used in a C^2 system.

In addition, one must consider the level of analysis being performed as shown in Figure 8-4: mission, system, or subsystem. Mission analyses are designed to address the contribution of the C^2 system to the force structure of which it is a part. System analyses involve assessment of the C^2 system's ability to operate with regard to some standard. Subsystem analyses are limited to some component of the system and measure performance.

Thus to properly analyze a system, the objective must be determined as a function of life cycle and analysis type. This determination will also yield the model type required for the analysis. A set of sample measures may also be developed, a priori, from which to select the desired measure. Specific examples of these measures are presented in Chapter 6.

Chapter 7 develops both a probabilistic model and a deterministic model for generating measures in a structured fashion. The probabilistic model generates a stopping rule for how many measures are needed to fully represent a system. Although more conceptual than computational, this rule is an important step forward in the search for "how much is enough?" The deterministic model shown in

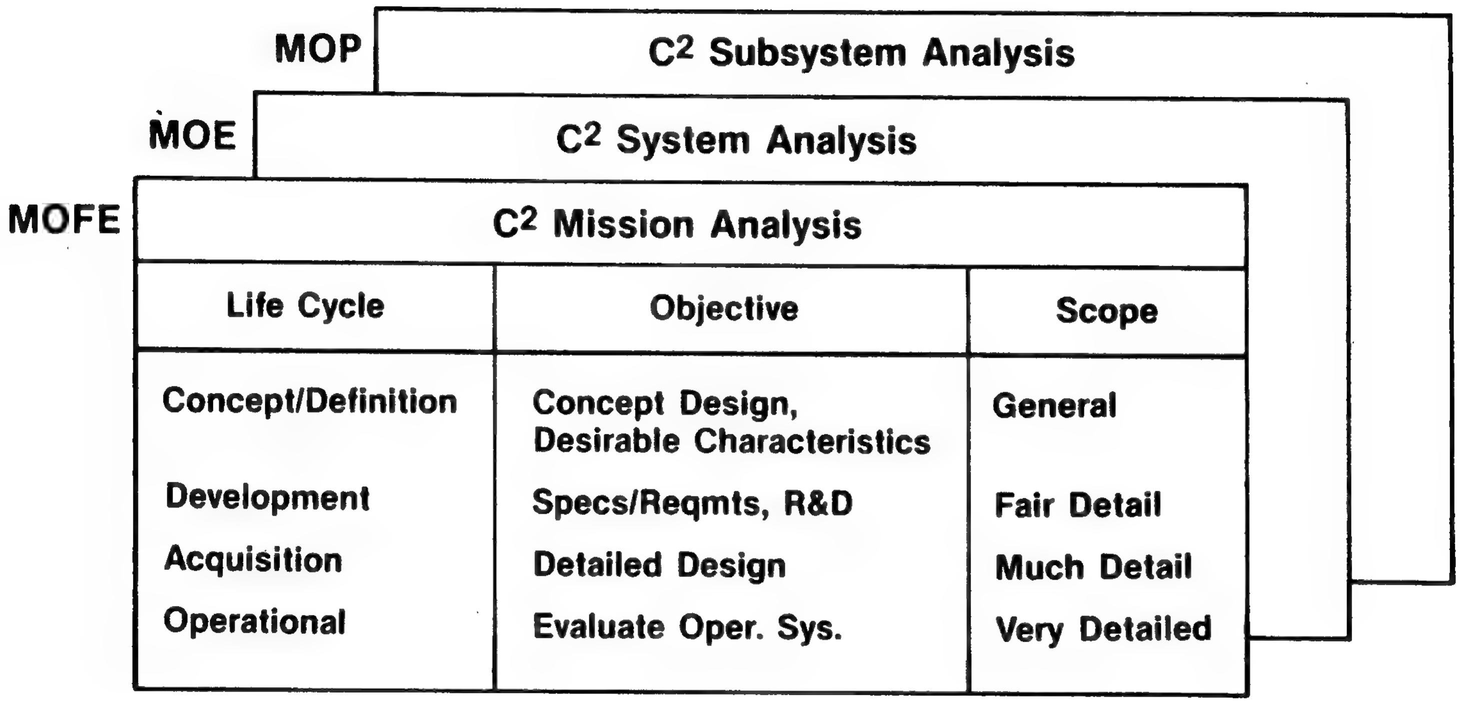


FIGURE 8-4
TYPES OF ANALYSES

Figure 8-5 separates the efforts of examining the tradeoffs necessary in C^2 system design into two categories: those relevant to the engineer and those important to the operations analyst. This formula for cooperation of these two communities may also represent a concept that will make future C^2 measures far more enlightening to decisionmakers. Thus, the Workshop has made important contributions to understanding C^2 evaluation from a mathematical point of view.

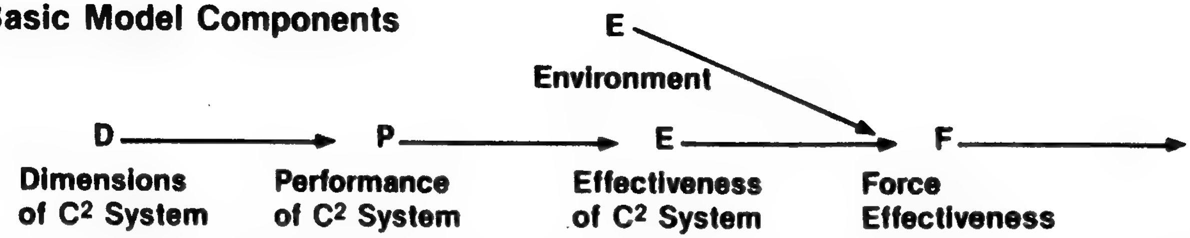
Summary and Proposal for the Next Step

This report contains an important proposal for an evaluative structure and many insights for the evaluation of C^2 systems. However, the proposed structure remains to be tested. Application studies to test the structure are needed. These studies must attack real problems using existing and newly developed tools guided by the framework set forth by the evaluation architecture. If the evaluation structure provides realistic solutions, we can be more confident as to the validation of the approach. If it is productive, then the limits of its productivity should be tested. However, if it is not useful, then we need to determine the reasons and how it should be modified. Finally, the evolutionary nature of the topic precludes considering any part of this report as a finished issue. We are trying to develop a structure that will be useful to the community. In doing so, the formulations change but maintain a common thread.

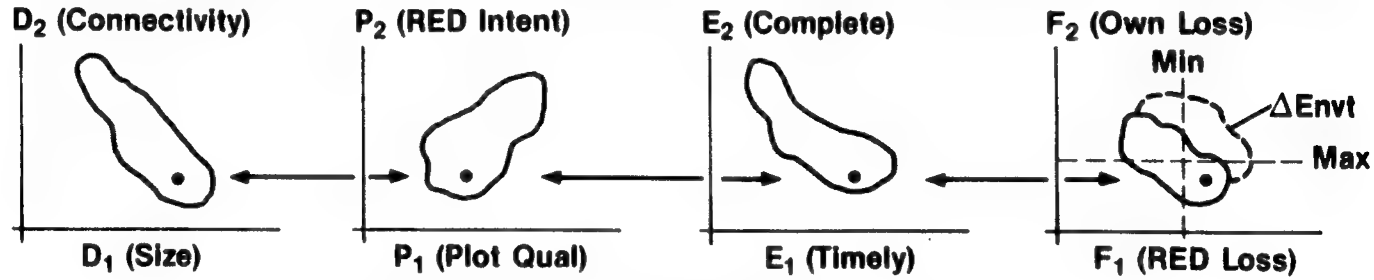
A meeting will be held in January 1986 to test the architecture with several real problems confronting Military Service and joint arenas, ranging from air defense to strategic nuclear C^2 and Navy battle group issues.

In order to provide a simplified, testable procedure at that meeting, we are reconfiguring the architecture of this report into a chain of modules (Figure 8-6). It takes the application objectives and bounds the system in accordance with our definitions. It then

- **Basic Model Components**



- **Mappings to Relate C² Dimensions, Performance, Effectiveness, Force Effectiveness**



  - Derive Effectiveness E Requirements from Force Goals F
  - Relate Performance P to Effectiveness E
  - Relate Dimension D to Performance P
  - Compare Alternative Systems by Changing E Requirements
  - Test Individual System by Varying Environment R

- **Sensitivity Formulation**

FIGURE 8-5
CONSTRUCTIVE (MODULAR) APPROACH

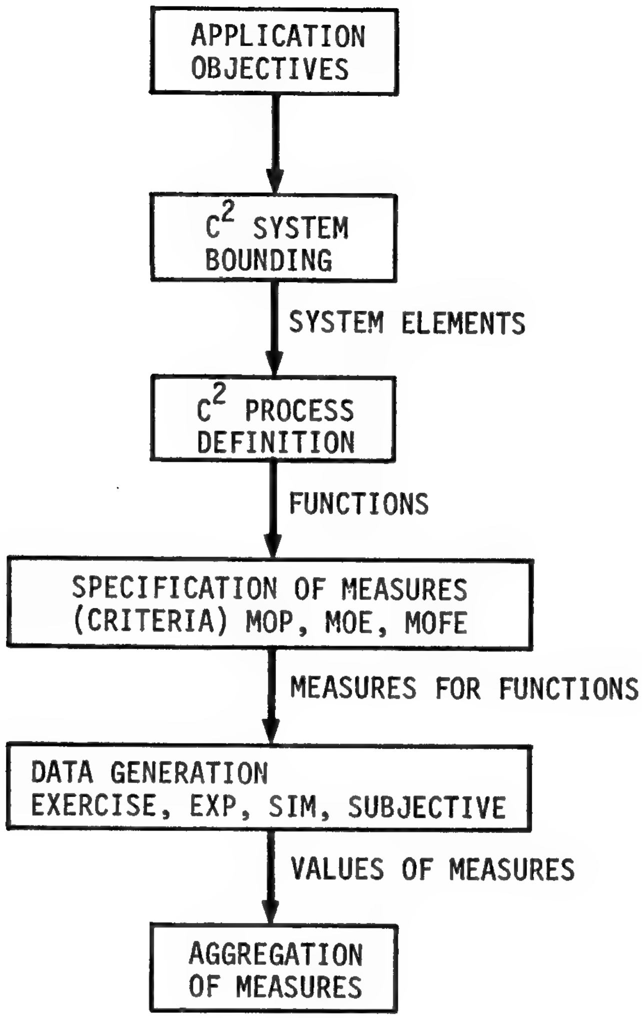


FIGURE 8-6
MODULAR C^2 EVALUATION STRUCTURE (MCES)

continues with the conceptual model in the development process described in the Model chapter and in Figure 8-2 to produce a specific C^2 process model. Next, the measures of performance, effectiveness, and force effectiveness are selected according to the criteria presented in Chapter 6. Data generation techniques are then applied: models, exercises, and subjective evaluations. These resulting measures are tested, combined, and summarized as discussed in Chapter 7. Finally, these results are returned to the decision-maker for interpretation, assessment, and possible generation of additional alternatives. This more workable formulation of the material in the report and in our next Workshop will test this approach.

The reader should be reminded that the endeavour reported herein is a dynamic one. Even as this document was being written the editors and other participants were evolving the concepts presented. As we tried to even out this report to reflect the current thinking we found that we kept rewriting. We have, therefore, chosen to freeze the document to represent November 1985, knowing that evolution of these concepts will continue. We hope to provide the community with a testable, although transient, formulation for the evaluation of C^2 systems. While theory moves on, this will present a structure to help in communicating and framing the analyses so badly needed in this area.

APPENDIX A

C^2 MOE WORKSHOP SPECIAL SESSION

C^2 MOE Workshop Special Session

53rd MORS — U. S. Air Force Academy

C^2 Workshop
A Building Block Approach

Genesis of NPS C^2 MOE Workshop

- Gen. Eaglet, AFSC, Challenged ESD to Evaluate the Effectiveness of C^3I Systems
- ESD Tasked MITRE to Ascertain How
- MITRE Approach
  - Determination of Baseline
  - Build Upon the Shoulders of Giants
  - Develop a Generic (or Specific) Methodology

1984 C^3I Measures of Effectiveness Symposium

MITRE, Bedford, MA Feb. 28 to Mar. 1, 1984
Chairs: Dr. Ricki Sweet   Lt. Col. Thomas Fagan, III

- Parallel Working Group Concept
  - Working Definitions
  - MOE Identification
  - Evaluation Techniques
- Five Working Groups
  - Dr. Zitta Z. Friedlander, The MITRE Corporation
  - Griffin S. Hamilton, EASTAN Corporation
  - Linda M. Hill, SAI
  - Dennis K. Holstein, LOGICON
  - Richard Hu, Naval Sea Systems Command

Symposium Focus

- C^3I Model
- Transfer Function
- Analysis Objectives
- Standard Terminology
- Methodology
- MOE Applications
- Decision Making and Decision Makers

52nd MORS C^3 (MOE) WG

Chairman: Dr. Ricki Sweet, MITRE

Presentations by:

Theodore Jarvis, MITRE	Dr. Morton Metersky, NADC
Lt. Col. Edward C. Jonson, ESD	Dr. Ricki Sweet, MITRE

Symposium Working Group Chairs

Proposal for MORS Sponsored Interim Workshop

Dr. Morton Metersky, Naval Air Development Center

Dr. Michael Sovereign, Naval Postgraduate School

Dr. Ricki Sweet, The MITRE Corporation

C^2 Measures of Effectiveness Workshop

Experimentation

Intergroup Coordinators	Draft Publication

Working Group Concept

Working Group Chairs

Dr. Stuart Brodsky, Sperry	Dr. Walker Land, IBM
Dr. William Foster, MITRE	Richard "Hap" Miller, USA TRASANA

Intergroup Coordinators

Edward Brady, MITRE	CDR Paul Girard, ONR
Dr. Norval Broome, MITRE	Griffin Hamilton, EASTAN
Dr. John Dockery, OJCS	Dr. Joel S. Lawson, Jr. NAVELEX (Ret)
Dr. Zitta Friedlander, MITRE	Dr. Martin Leonardo, NADC

Symposium Results

- Assessed State-of-the-Art
- Projected the Course of MOEs for the Future
- Prepared Groundwork for Follow-On

Standard Terminology

- Necessary if a Theory of C^2 is to be Established
- Needed to Promote Development of an Organized Body of Facts
- Required for Consistency within Community
- Needed to Reduce Controversy

Proposed Definitions

Command and Control

- Broad Concept Useful for Specific Analyses
- Does Not Include Weapon Systems

"The Exercise of Authority and Direction by a Properly Designated Commander Over Assigned Forces in the Accomplishment of His Mission..." JCS Pub 1

Proposed Definitions
(Continued)

C^2 System — Viewed as Having Two Components

- Physical Entities: Equipment (e.g., Computers and Peripherals, Modems, Jammers, Computer Networks, Communications), Software Facilities, and People
- Structure: The Arrangement and Interrelationship of Physical Entities, Procedures, Protocols, Concept of Operations, Information Patterns, etc.

Supported by JCS Pub 2 Definition of Command, Control and Information System

Proposed Definitions
(Continued)

C^2 Process: Portrays What System is Doing and Reflects Functions Performed by C^2 System: Sensing, Interpreting, Deciding and Acting

Boundary — Delineation Between System Being Studied and the Milieu

Measured/Specified Inside C^2 System Boundary

- Parameters
- MOP

Measured/Specified Outside C^2 System Boundary

- MOE
- MOFE

Proposed Definitions
(Continued)

Parameters: Properties or Characteristics in the Physical Entities Whose Values Determine System Behavior and the Structure Under Question Even When at Rest (e.g., Size, Weight, Number of Pixels, Luminosity)

MOP: Related to Inherent Parameters (Physical and Structural) But Measure Attributes of System Behavior (e.g., Gain, Throughput, Error Rate, S/N)

MOE: Measure of How C^2 System Performs Its Functions within an Operational Environment (e.g., Reaction Time, Susceptibility to Jamming)

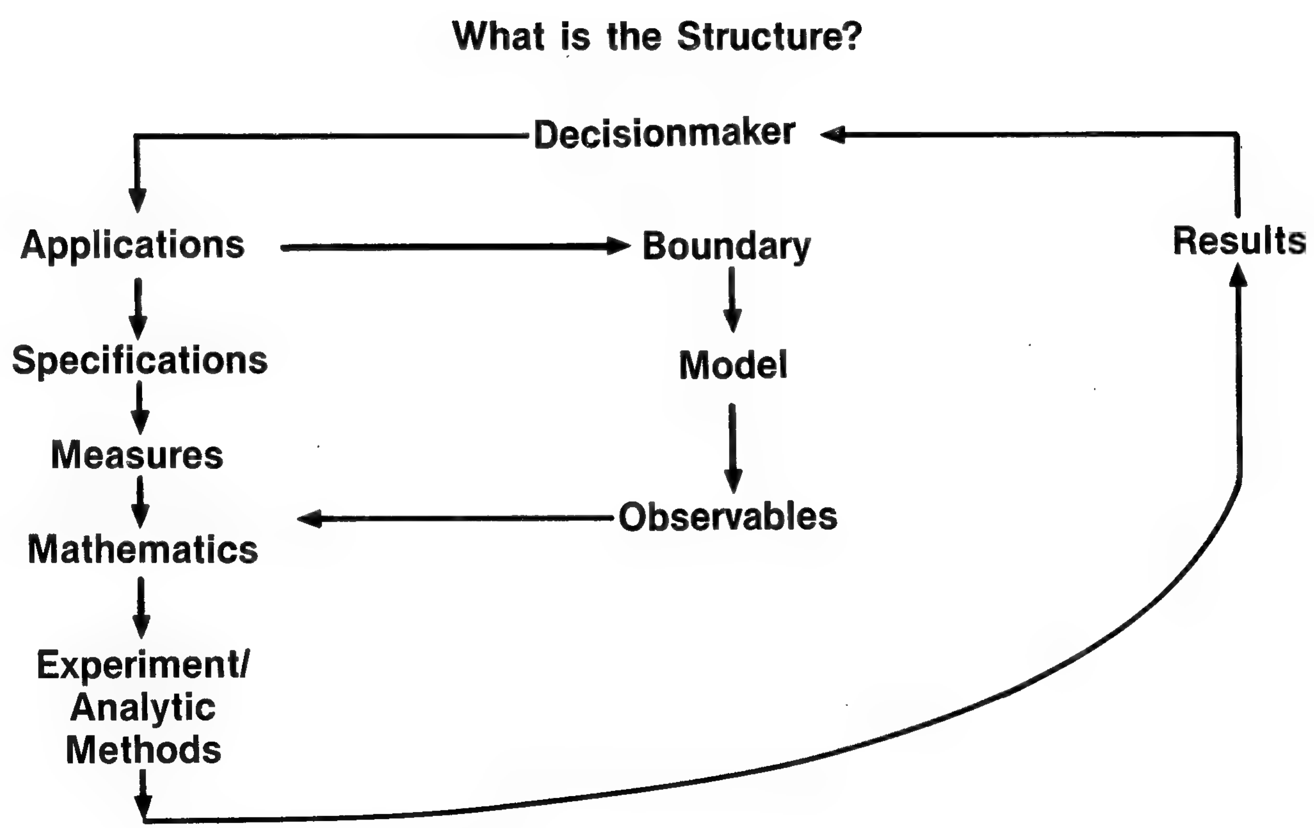
MOFE: Measure of How C^2 System, and the Force of Which It is a Part, Performs Missions

Structure — Architecture

Outline

- What is the Structure?
- Some Contributions of the Working Groups
- What Do We Still Need?
- Building Blocks We Have
- Concluding Remarks

Structure — Architecture



Structure — Architecture

Some Contributions of the Working Groups

- The Blueprint — Applications
- The Foundation — Search for a Generic Model
- The Tools — Measures
- The Tools — Mathematics

Structure — Architecture

The Blueprint — Applications

- Applications Areas
  Concepts, Design, Acquisition, Operations
- Analysis Objectives
  Evaluation, Allocation
- Assessments
  Individual, Comparative
- Boundaries

Structure — Architecture

The Foundation — Search for a Generic Model

- What is Generic?
- Blueprint and Foundation — Applications and Models
- Working Group Focus

Structure — Architecture

The Tools — Measures

- Blueprint, Foundation, Tools — Measures
- Measures and the Generic Model
- Measures and Data Collection

Structure — Architecture

The Tools — Mathematics

- Calculation of Effectiveness
- Probabilistic and Deterministic Models

Structure — Architecture

What Do We Still Need?

- Missing Pieces
- Testing the Architecture
- Do We need a Generic Model?
- Using the Architecture

Structure — Architecture

Building Blocks We Have

- Evaluation Architecture Made Explicit
- Objectives and Evaluation Made Explicit
- Analysis Tied to Decisions
- Nature of C^2 System Specified
- Measures Tailored to Analytic Model
- Probabilistic Approach to Mathematics Formulated

MORS General Session

- Applications Working Group
  - — Felt the Necessity to Determine Why MOE Applications Have Failed to Materialize
  - — Developed a Dichotomy Consisting of Conceptual and Implementation Categories
    - This Approach May Bother Old Hands
    - Group Felt That "Implementation" Was Familiar and Therefore Received More Attention
    - "Implementation" Relates to More Traditional Processes
      - — POM
      - — Acquisition
      - — Technical Evaluation
      - — Operational Evaluation
  - — Conceptual Category Far Less Developed
    - Doctrine Development
    - Requirements Generation/Validation
    - New Technology Assessment
    - R & D Goals

Applications Working Group

- Preliminaries to January Symposium
- Composition of Applications Working Group
  - Col. Bud Allison, USA-JCS
  - Bob Choisser, DCA
  - Dr. Bill Foster, MITRE
  - Griff Hamilton, EASTAN
  - Dr. Marty Leonardo, NADC
  - Lt. Col. Ed Jonson, USAF-ESD
  - Mike Michail, NOSC
  - Maj. Larry Rhoads, USMC-MCTSSA
  - Capt. Bernard Galing, USA

MOE Applications — Blueprint

- Applications Treatise Written by Teams and Integrated
- Daily Update Was Accomplished on the Macintosh
- Draft Was Produced at End of the Workshop
- Organization
  - Description of Areas for MOE Application
  - Discussion of Considerations for Applications
  - Guidelines for Specific Applications
  - Examples of MOE Applications (Strategic, Tactical, Joint)
  - Conclusions/Recommendations for Application
    - Process of Application
    - Realities of MOE Applications

Foundation-Search for a Generic Model

Prepared for June 1985
MORS Special Session
Report on C^2 Workshop

By Walker H. Land, Jr.

Content

- Working Group Participants
- Objectives
- Approach
- Achievements
- Evaluation and Remaining Issues

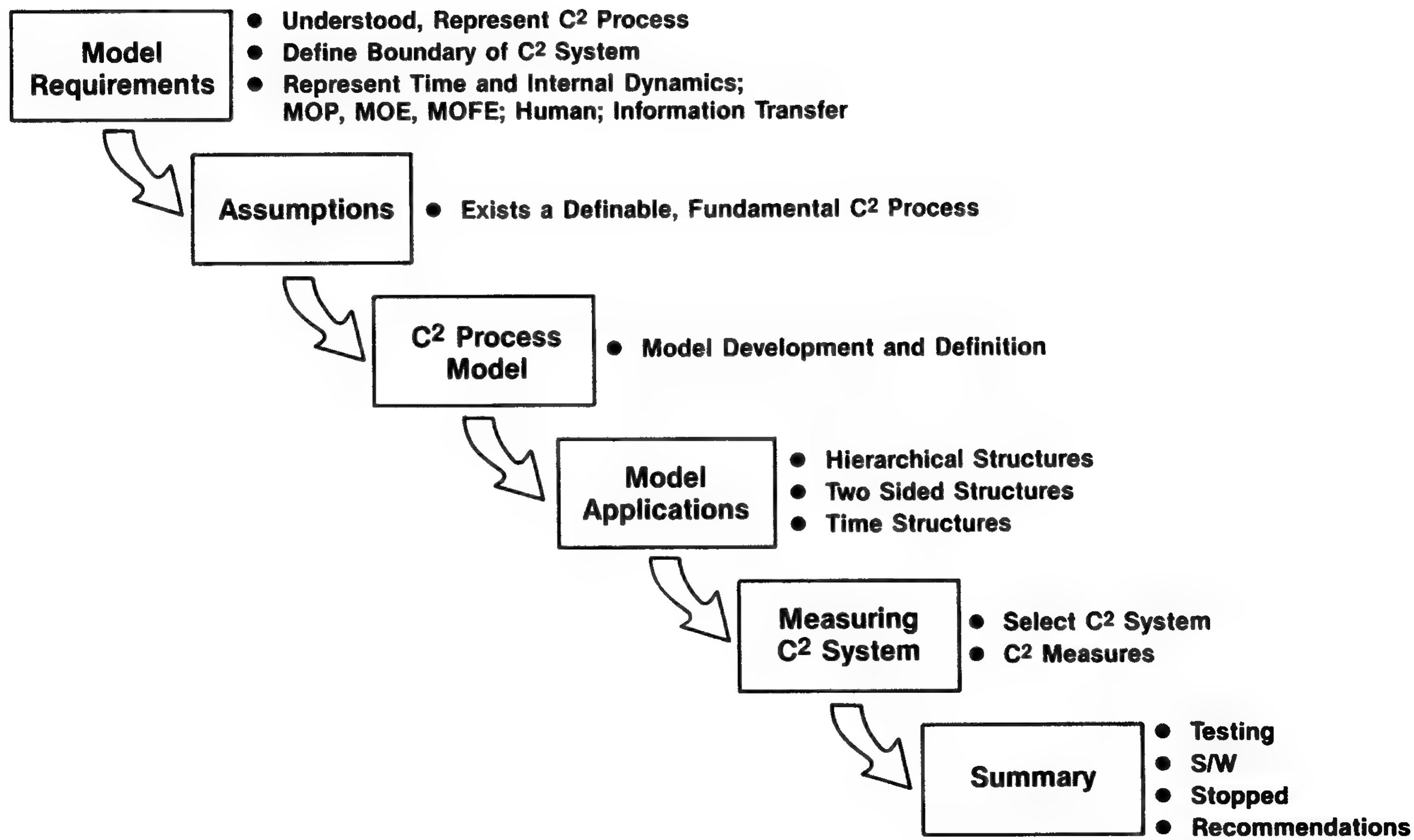
Working Group Participants

Walker Land	IBM
Judith Grange	Science Applications International Group
Tony Snyder	Roam Air Development Center
Leon Godfery	Fort Leavenworth
Ted Bean	MITRE Corp.
Don Newman	NAVAIR

Objectives

- Develop a C^2 Conceptual Model and Apply This Model
- Test Developed Model Using Experience of Working Group Members and Intergroup Coordinators
- Establish, if Possible, Strengths and Weaknesses of the Developed Model
- Identify Specific Recommendations Resulting from the Workshop Deliberations

Approach



Model Requirements
• Understood, Represent C2 Process
• Define Boundary of C2 System
• Represent Time and Internal Dynamics; MOP, MOE, MOFE; Human; Information Transfer
Assumptions
• Exists a Definable, Fundamental C2 Process
C2 Process Model
• Model Development and Definition
Model Applications
• Hierarchical Structures
• Two Sided Structures
• Time Structures
Measuring C2 System
• Select C2 System
• C2 Measures
Summary
• Testing
• S/W
• Stopped
• Recommendations

Achievements

- Generic Model Established Which
  - Met Model Requirements
  - Was Applied to
    - Hierarchical Systems
    - Two-Sided Systems
    - Consideration of Time
- Showed that C^2 Process Model Can be Used to
  - Clarify Part of C^2 System Which Needs Evaluation
  - Related Following Measures to Model
    - MOPs
    - MOEs
    - MOFEs

Evaluation and Remaining Issues

- Preliminary Testing
  - Subjected to Tests Designed to Exhibit its Adaptive Properties While Maintaining Fundamental Property
- Strengths
  - Simplicity of Model ➧ C^2 Process Easily Visualized as Ordered Arrangement of Elemental Blocks
  - Ordered Arrangements ➧ Mathematical Modeling
  - Complex Systems May be Selectively Decomposed
- Weaknesses
  - Lumped Functions Do Not Completely Describe Distributed Process System
  - Dynamic Representation of System Not Attempted
    - Time Sequence Stop Frame Approach May Work
  - Questions Remain Concerning
    - Positioning of Functional Elements of Model Within Environment
    - Exact Entry Point for Desired State Stimulus

Evaluation and Remaining Issues
(Continued)

- What We Did/Where We Stopped
  - Developed Conceptual Model and Applied it to Hierarchical, Two-Sided, and Timed Structures
  - Tested Model Using Working Group Participants and Intergroup Coordinators
  - Stopped When Did the Above
- Recommendations
  - Must Apply Model to Large Range of Problems and Communicate Results (Successes and Failures) to C^2 Community
  - Feeling was that Model was Produced Which Could be Core of C^2 Analysis
    - Painfully Aware of Need for Scrutiny from Wider Audience of C^2 Analysts Over Longer Time Period

Tools — Measures

A Measure
A Term Used to Assess the Ability of a System

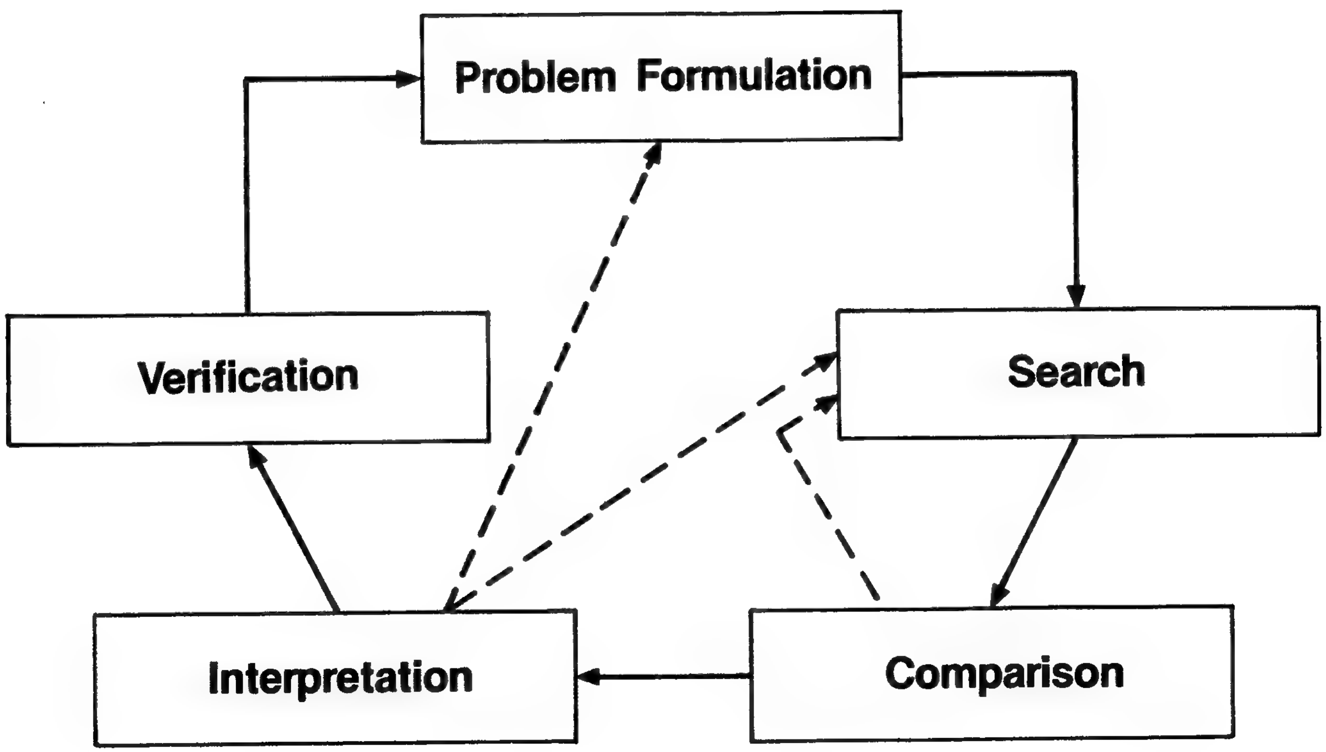
MOE Specification Working Group

• Hap Miller, Chairman	USA/TRADOC
• Hal Glazer	MITRE
• Linda Hill	SAIC
• Charlie Smith	ANSER
• Capt Bruce Thieman	OJCS

Specification of Measures

- Analytic Process and Role of Measures
- Relationship Between:
  - Phases of System Life Cycle
  - Scope of Analysis
  - Objective of Analysis
  - Selection of Measures
  - Selection of Models
- Characteristics of Measures
- Specification of Measures

The Analysis Process



Types of Analyses

MOP — C^2 Subsystem Analysis

MOE — C^2 System Analysis

MOFE — C^2 Mission Analysis

Life Cycle	Objective	Scope
Concept/Definition	Concept Design, Desirable Characteristics	General
Development	Specs/Reqmts, R&D	Fair Detail
Acquisition	Detailed Design	Much Detail
Operational	Evaluate Oper. Sys.	Very Detailed

Objectives, Models and Sample Measures for C^2 Mission Analyses

Issue / Life Cycle Phase	Objective	Model Scope	Sample Measures
Conceptual	Determine the Desirable Force/C^2 System Characteristics	Broad, Interactive, Very General	Outcomes — Win, Lose, Draw Status vs. Time (U.S. vs. Enemy) — Force/C^2 Capab. — No. Deliverable/Commandable Weapons — No. Targets Destroyed — Timeliness of Responses — Ability to Respond Appropriately
Definition	Develop a General Definition and Desired C^2 System Capability	Broad, Interactive, Fair Detail, Especially in C^2 Area	
Acquisition	Determine if the C^2 System as Designed Supports the Desired Force/C^2 System Capability	Broad, Interactive, Much Detail, Especially in C^2 Area	Same as Above
Operational	Evaluate the Operational C^2 System Capability to Achieve Desired Outcomes for Particular Scenarios	Broad, Interactive, Very Detailed (Including Use of Actual Systems)	Same as Above

Objectives, Models and Sample Measures for C^2 System Analysis

Life Cycle Phase / Issue	Objective	Model Scope	Sample Measures
Conceptual	Determine the Desirable C^2 System Characteristics	System, Some Threat, Closed Loop, General	— Survivability/Endurance — Types of Info Available — Timeliness of Data — Decision Response Time
Design	Develop the C^2 System Requirements, Determine Current System Capabilities, Deficiencies, and Select "Best" of Alternative System Definitions	System, Threat, Environment, Closed Loop, Fair Detail	• For Sensors, Accuracy/ Timeliness of Displayed Info • For Communications, Capacity, Number Channels • For Command Centers, Display Refresh Time, Ease of Comprehension of Info
Acquisition	Determine "Best" Design; Test and Evaluate Developmental System	System, Threat, Environment, Open and Closed Loop, Much Detail	
Operational	Evaluate the Operational C^2 System to Determine if Its Performance Meets the Specifications or Requirements	System, Simulated Threat and Environment, Open and Closed Loop, Much Detail	Same as Above

Objectives, Models and Sample Measures for C^2 Subsystem Analysis

Issue / Life Cycle Phase	Objective	Model Scope	Sample Measures
Conceptual	Determine the Desirable Force/C^2 System Characteristics	Broad, Interactive, Very General	Outcomes — Win, Lose, Draw Status vs. Time (JS vs. Enemy) — Force/C^2 Capability — Number of Deliverable/Commandable Weapons — Number of Targets Destroyed — Timeliness of Responses — Ability to Respond Appropriately
Design	Develop a General Definition and Desired C^2 System Capability	Broad, Interactive, Fair Detail, Especially in C^2 Area	
Acquisition	Determine if the C^2 System as Designed Supports the Desired Force/C^2 System Capability	Broad, Interactive, Much Detail, Especially in C^2 Area	Same as Above
Operational	Evaluate the Operational C^2 System Capability to Achieve Desired Outcomes for Particular Scenarios	Broad, Interactive, Very Detailed (Including Use of Actual Systems)	Same as Above

Desired Criteria for Measures

Characteristics	Definition
Mission Oriented	Relate to Force/System Mission
Discriminatory	Identify Real Differences Between Alternatives
Measurable	Able to be Computed, or Estimated
Quantitative	Able to be Assigned Numbers, or Ranked
Realistic	Relate Realistically to the C^2 System and Associated Uncertainties
Objective	Defined, or Derived, Independent of Subjective Opinion. (It is Recognized that Some Measures Cannot be Objectively Defined.)
Appropriate	Relate to Acceptable Standards and Analysis Objectives
Sensitive	Reflect Changes in System Variables
Inclusive	Reflect Those Standards Required by the Analysis Objectives
Independent	Mutually Exclusive with Respect to Other Measures
Simple	Easily Understood by the User

Analytic Approaches

- Analysis Using System Models
- Analysis Using Actual System

Illustration of Modeled C^2 System Analysis

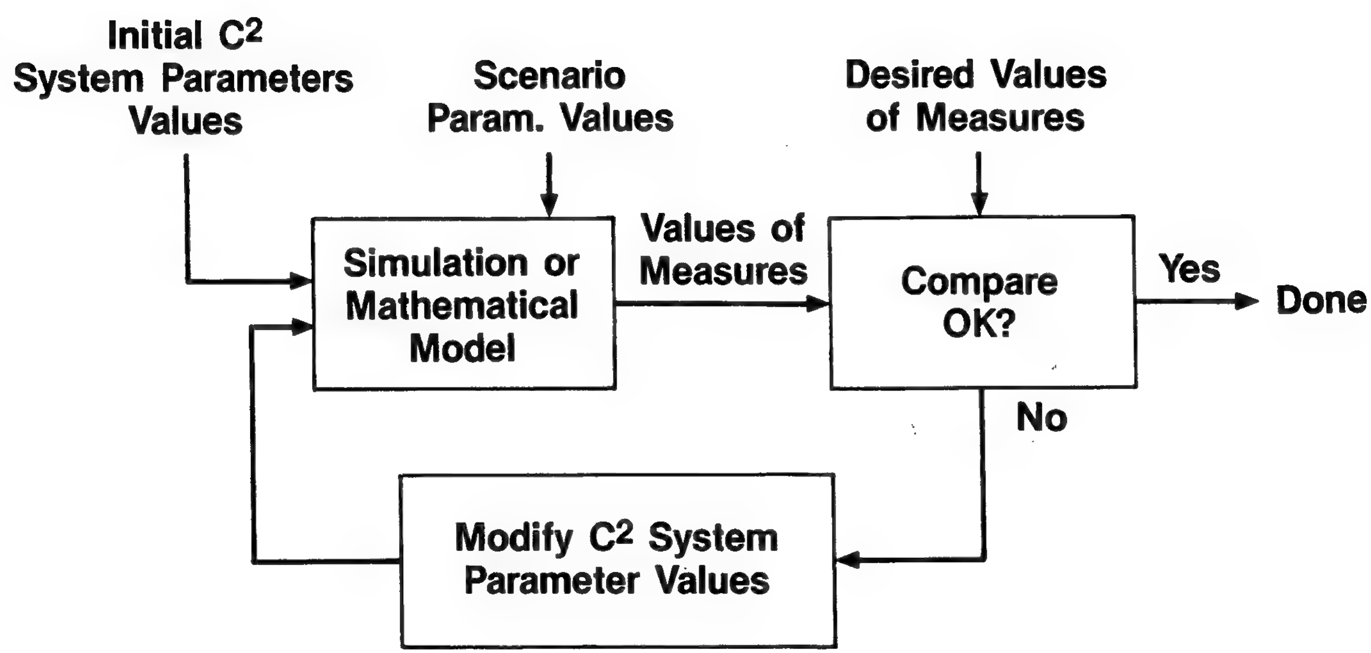
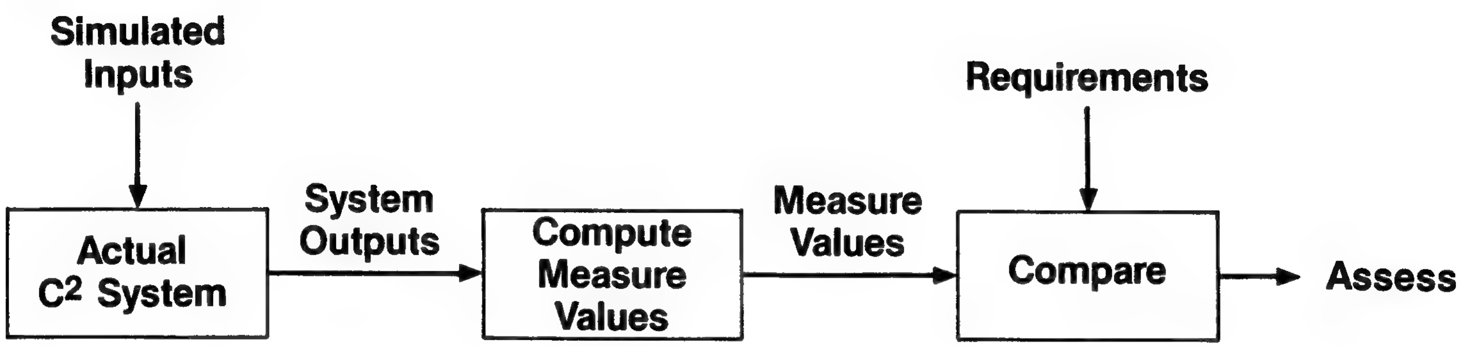


Illustration of Actual C^2 System Analysis



C^2 MOE Workshop
Tools: Mathematical Formulation

Prepared For:

June 1985 MORS
Special Session
on C^2 MOE

Contents of Presentation

- Working Group Participants
- Objectives
- Technical Approach
- Principal Results
- Evaluation and Issues

Mathematical Formulation Working Group

• Stuart Brodsky, Chairman	• Sperry
• Alex Levis	• MIT
• Tony Richardson	• CNA
• Conrad Strack	• DSI
• Edison Tse	• Stanford
• Clairice Veit	• RAND

Objectives and Technical Approach

- Generic Formulation to Identify Inevitable Model Components and Linkages
- Definite Modeling Strategies for Integrated But Separable Models
- Integrate C^2 Attributes, Effectiveness, Combat Outcomes, and Environment

Probabilistic Formulation

- **Basic Model Components**

$$S \longrightarrow V \longrightarrow C$$

S	V	C
C^2 System	Variables to Measure C^2 Effectiveness	Combat Outcomes

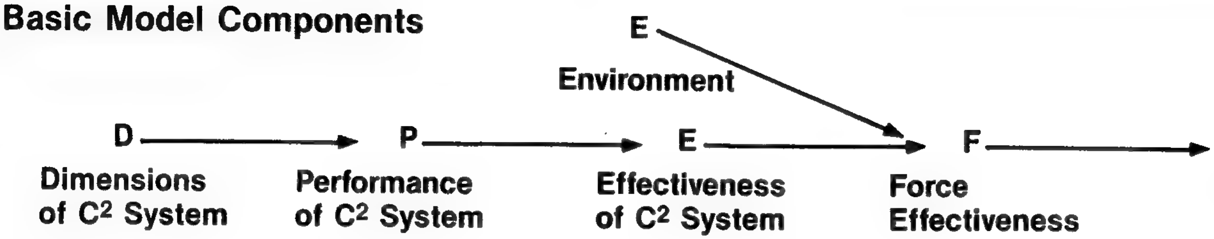
- **Defining Adequate V Variables to Measure C^2 Effectiveness**

  If $P(C/V,S) = P(C/V)$,
  Then V is Sufficient Set of Measures

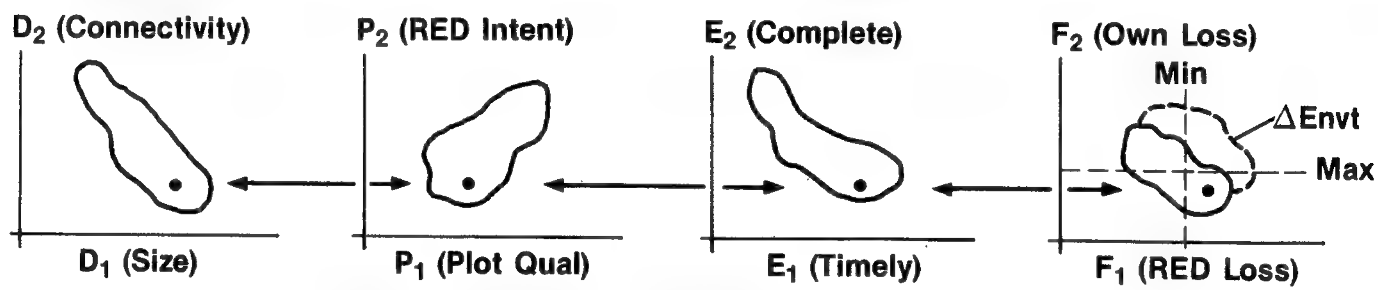
- **Modeling C^2 Requirements and System Responsiveness**
  - Specify Acceptable Outcome C as Conditional Upon C^2 Performance V at Confidence Level K — $P(C/V) > K$
  - Effectiveness of C^2 System S Defined By Conditional Probabilities: — $E_S = P(C/V)\,P(V/S)$
    - Of Outcome C Upon Performance V
    - Of Performance V Upon System S

Constructive (Modular) Approach

- **Basic Model Components**



- **Mappings to Relate C^2 Dimensions, Performance, Effectiveness, Force Effectiveness**



  - Derive Effectiveness E Requirements from Force Goals F
  - Relate Performance P to Effectiveness E
  - Relate Dimension D to Performance P
  - Compare Alternative Systems by Changing E Requirements
  - Test Individual System by Varying Environment R

- **Sensitivity Formulation**

$$dF = \frac{\partial F}{\partial E}\frac{\partial E}{\partial P}\frac{\partial P}{\partial D}\,dD + \frac{\partial F}{\partial R}\,dR$$

Assessment of Results

- Summary of Results
  - — Generic Formulation of Inevitable C^2 Model Components and Linkages
  - — Definition of Two Essential Modeling Dimensions:
    - Probabilistic Formulation to Reflect Uncertainty and to Test for Model Completeness
    - Component Formulation to Integrate C^2 Attributes, Effectiveness, and Combat
- Next Steps
  - — Exploration of Component Models' Structures and Contents
  - — Refinement of Model Structure From Empirical Findings

Special Session Agenda

- Structure — Architecture
- Blueprint — Applications
- Foundation — Search for a Generic Model
- Tools — Measures
- Tools — Mathematics
- A Bridge to the Future

Accomplishments

1. Proposed Definitions
2. Proposed Process Model of Command and Control (C^2)
3. Proposed Mathematical Model of C^2 and Example
4. Discussion of MOE Specification in Analysis and Examples
5. Discussion of Applications and Examples

Possible Next Alternative

1. Status Quo
2. Minor Updating of Separate Papers
3. Major Revision of 2, Above
4. Major Integration of Revised Papers
5. Complete Rewrite

Requirements for Completion

1. Minor: Groups Revise — 6 Months to Coordinate
2. Major: As Above Plus Another Meeting to Integrate Results — 1 Year

Possible Tasks for Future

Integrate and Improve the Monograph

Assemble Thesaurus Mapping Common Terms to the Architecture

Application to Representative Problems

Assemble Bibliography

Assemble Directory of Models

APPENDIX B

GLOSSARY

ADM	Advanced Development Model
ATO	Air Tasking Order
C^2	Command and Control
C^3	Command, Control, and Communications
C^3I	Command, Control, Communications, and Intelligence
DCT	Digital Communication Terminal
DOD	Department of Defense
IC	Intergroup Coordinator
JCS	Joint Chiefs of Staff
MCES	Modular Command and Control Evaluation Structure
MOE	Measure of Effectiveness
MOFE	Measure of Force Effectiveness
MOP	Measure (Variable) of Performance
MORS	Military Operations Research Society
NPS	Naval Postgraduate School
POM	Program Objectives Memorandum
R&D	Research and Development
SLBM	Sea-Launched Ballistic Missile
TWA	Tactical Warning/Attack Assessment
U.S.	United States
VFME	Variable for Measuring Effectiveness
WWDSA	Worldwide Digital System Architecture